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SOME STATISTICAL ASPECTS OF CIRRUS CLOUD

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ABSTRACT

A large body of aircraft reports is analyzed to provide information on the vertical and horizontal distribution of cirriform clouds in Canada. Other parameters are investigated including temperatures at the base of cirrus cloud, relationship of cloud tops with the tropopause, stratospheric cirrus, and visibility in cirriform clouds.

1. INTRODUCTION

This investigation grew out of a need for information on high-level clouds and visibilities. It was readily apparent that data based on surface observations would be highly inadequate. Much cirrus [1] cannot be seen from the ground either because it is too tenuous or because lower clouds are interposed. Surface estimates of cirrus heights are often grossly in error [1], and there is no way of estimating the depths of cloud layers from such observations. Many of the difficulties can be circumvented by the use of aircraft observation. A body of observations was available which had been taken by Royal Canadian Air Force pilots when engaged in routine flights. These reports are not made in any standard fashion and therefore vary considerably in accuracy. However the reporting errors involved are, for the most part, random in nature. About 2,500 such reports were analyzed for the purposes of the present investigation. The observations covered the period 1950–1956 although the majority were made in the years 1953–1956.

Over 2,000 of the reports were analyzed to determine the percentage occurrence of cirrus at 30,000 ft., 35,000 ft., 40,000 ft., and 50,000 ft. Only one case of cirrus was encountered at 50,000 ft. so that no tabulation was kept for this height. The percentages were arrived at by considering each flight as a sample of the atmosphere and noting the portions of the sky covered by cirrus at the

levels in question. In addition, a parameter which shall be referred to as "Total Cirrus" was also tabulated. This parameter indicates the percentage of the sky covered by cirrus, regardless of altitude or number of layers involved. It, therefore, corresponds to the figure of cirrus amount which would be reported by an observer on the ground if the lower cloud were transparent and the observer could detect all of the cirrus present.

Some 400 additional aircraft reports were analyzed separately for information on the base and tops of cirrus layers. In this analysis, temperature and tropopause values were deduced from radiosonde data and upper-air charts.

Murgatroyd and Goldsmith [2] and more recently James [3] carried out investigations on cirrus cloud over the British Isles, based on a more limited number of aircraft observations. Certain items such as heights of clouds and relationship of cirrus to the tropopause were investigated in the British papers and their results did not seriously differ from those reported here.

2. SOURCES OF ERRORS IN THE ANALYSES

The individual height and temperature values are subject to fairly substantial measurement errors. However, it is hoped that these errors are essentially random in nature and thus will not significantly affect the statistical results.

The samples used are, for the most part, large enough to give reasonably representative figures. However, in

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[1] In this report the terms cirrus and cirrus cloud are used interchangeably with cirriform cloud.

TABLE 1.—*Cirrus amounts as related to undercast and precipitation*

	30,000 ft. (%)	35,000 ft. (%)	40,000 ft. (%)	Total cirrus (%)	No. of flights
Unspecified cases	15.7	7.6	2.2	32.6	518
With undercast	25.3	9.6	1.8	44.9	565
With precipitation	38.7	15.3	2.1	59.6	94
Without undercast	8.7	4.4	1.8	20.9	912
Mean	15.2	6.7	1.9	30.7	1,995

TABLE 2.—*Cirrus amounts for specified geographic locations*

Area	30,000 ft. (%)	35,000 ft. (%)	40,000 ft. (%)	Total cirrus (%)	No. of flights
North Bay	14.8	6.1	1.6	30.3	1,423
Prairies	14.5	10.0	4.2	29.1	173
Eastern Canada	16.8	7.4	1.9	33.0	399
Mean	15.2	6.7	1.9	30.7	1,995

TABLE 3.—*Cirrus amounts for various times of year*

Period	30,000 ft. (%)	35,000 ft. (%)	40,000 ft. (%)	Total cirrus (%)	No. of flights
Warm months	18.4	10.2	3.6	31.8	628
Intermediate months	15.7	7.4	1.3	31.9	696
Cold months	11.8	2.8	0.9	28.7	671
Year	15.2	6.7	1.9	30.7	1,995

TABLE 4.—*Corrected cirrus amounts for various times of year*

Period	30,000 ft. (%)	35,000 ft. (%)	40,000 ft. (%)	Total cirrus (%)	No. of flights
Warm months	18.8	10.4	3.7	32.4	628
Intermediate months	16.0	7.6	1.3	32.6	696
Cold months	12.8	3.0	1.0	31.2	671
Year	15.6	6.9	2.0	31.8	1,995

common with other data of a climatological nature, there is always the possibility of even a large sample being abnormal. Nonetheless, certain internal checks indicate that most of the results are fairly stable.

There are some biases in the data which could affect the results. For example, reports of cirrus which did not specify heights had to be rejected. Since nil reports are not involved in these rejections, this reduces the calculated percentage occurrence of cirrus. On the other hand, pilots report occurrences of phenomena more faithfully than non-occurrences. This preference results in an error in the opposite sense and so may compensate for the first bias. In any case, a study of the order of magnitude of these errors indicates that they are not large so that their net effect can fairly safely be ignored. As a result of reporting errors there may have been some clouds included which were actually not cirriform. Ludlum [4] indicates that somewhere between −10° C. and −30° C. ice cloud rather than water cloud becomes the stable form. It was therefore decided to reject all clouds whose base was warmer than −20° C. If some cirrus was thereby rejected, it was hoped that this would counterbalance the failure to reject other non-cirriform cases. However, only a limited number of cases are involved so that this rough assumption will not seriously affect the results.

3. VARIATION OF CIRRUS AMOUNTS WITH UNDERCAST AND PRECIPITATION

Cirrus cloud will be more prevalent in areas of large-scale ascending motion. Thus, there should be increased amounts of cirrus when lower cloud layers and precipitation are present. Accordingly, the reports were subdivided into: (a) unspecified cases, (b) cases with an undercast, (c) cases with precipitation, (d) cases without an undercast. It should be noted that the instances with an undercast include those with precipitation. Table 1 lists the mean percentages of the sky covered by cirrus under the various conditions. We see that the distribution for the "unspecified cases" is similar to the overall distribution. Since the unspecified cases were arrived at

by a random process this suggests that the results are dependable.

4. GEOGRAPHIC VARIABILITY OF CIRRUS

The reports were subdivided into the following three geographic areas: (1) Eastern Canada (southern Quebec and New Brunswick), (2) Prairies (Alberta, Saskatchewan, and Manitoba), (3) North Bay area (in Ontario). Table 2 lists the percentage occurrence of cirrus for each of these areas. There does not appear to be much geographic variability, particularly if we bear in mind that the Prairie figures are based on a relatively small sample. It would be unsafe to assume that the homogeneity indicated by table 2 extends to regions with radically different climatic regimes.

5. SEASONAL VARIABILITY OF CIRRUS

An analysis was carried out to see whether there was any seasonal variation in the occurrence of cirrus. Table 3 lists the results of this analysis where the "warm months" refer to June, July, August, and September; the "intermediate months" are March, April, May, and October; and the "cold months" November, December, January, and February.

Although there are differences between the seasons in the vertical distribution of cirrus, the "Total Cirrus" amounts do not vary a great deal. The cold months show a somewhat lower figure but there is a correction to be applied before this reduced amount can be accepted as real. The necessity for this correction stems from the fact that there is more bad flying weather in winter than in other months although there are increased cirrus amounts associated with bad weather. In order to calculate the magnitude of this effect, the percentage occurrences, for each of the periods, of either ceilings below 500 ft. or visibilities below one mile were determined from climatological records [5] and it was considered that there would be no flying under such circumstances. It was then assumed from table 1 that the "Total Cirrus" was

TABLE 5.—*The base and tops of cirrus layers (thousands of feet)*

(a) According to Seasons

Season	Base	Top	H_{max}
Warm months	28.5	33.5	31.0
Intermediate months	25.5	30.1	27.8
Cold months	24.5	29.4	26.9
Year	26.2	31.0	28.6

(b) According to Cirrus Amounts

Cloud amount	Base	Top	H_{max}
Overcast	24.8	33.0	28.9
Broken	25.0	30.0	27.5
Scattered	26.7	29.3	28.0
Mean	25.5	30.8	28.1

NOTE: H_{max} is midway between the mean top and bottom of the cloud.

TABLE 6.—*Thickness of cirrus layers (thousands of feet)*

Season	Top minus base from table 5a	From areas of figure 1	By using 400 check reports
Warm months	5.0	6.5	6.7
Intermediate months	4.7	6.0	6.3
Cold months	4.9	5.6	6.0
Year	4.9	6.0	6.3

FIGURE 1.—Percentage occurrence of cirrus versus height, for various seasons.

45 percent for the portion of the time when flying conditions were poor and 30 percent at other times. It was thus possible to arrive at the figures of table 4 which removed the bias due to the fact that more flying takes place in relatively good weather. Although the corrections are small they reduce the differences in the "Total Cirrus" percentages between the cold months and the other months. Comparing the yearly values in tables 3 and 4 it appears that a correction of about one part in thirty could be applied to the percentages of tables 1 and 2 to allow for this effect.

6. THE BASE AND TOP OF CIRRUS

An independent group of over 400 North Bay reports was analyzed with reference to the base and tops of cirrus layers and some of the results of this analysis are incorporated in table 5. The level of maximum occurrence of cirrus, H_{max}, is also listed and this is taken as the level midway between the mean top and bottom of the cloud. The mean values in the two parts of table 5 are not identical since some reports did not specify cloud amounts.

7. VERTICAL DISTRIBUTION OF CIRRUS

Using the percentages of table 4 and the heights of maximum occurrence of cirrus from table 5(a), the upper halves of the curves of percentage occurrence of cirrus versus height were drawn as shown in figure 1. The problem of a unique interpretation of the data was reduced by assuming that the curves for the three parts of the year were fairly similar and parallel. Since this realistic assumption can be made without significantly violating the data, we can conclude that the distributions are reasonably dependable.

8. THICKNESS OF CIRRUS LAYERS

The mean thicknesses of cirriform layers can be derived by subtracting the mean heights of the base from the tops using the values of table 5 (a). Also, on the assumption that there is as much cirrus below the height of maximum occurrence as above, mean thicknesses were obtained using the curves of figure 1 and the "Total Cirrus" percentages. About 400 of the original body of 2,000 reports could be analyzed for cloud thickness and this was done. These three sets of thickness values are listed in table 6. The figures based on the data of table 5 (a) are somewhat lower than the others. However, these results were based on an independent body of reports and the sample may have been somewhat abnormal. The good agreement between the other two sets of values suggests that the frequency distributions of figure 1 are reasonable and that the effects due to contamination of the data by non-cirriform clouds are negligible.

9. TEMPERATURES AT THE BASE OF CIRRUS

The formation of cirriform clouds usually takes place on ice nuclei and these become active over a fairly wide temperature range. It has been suggested (see, for example, Ludlum [4]) that below a temperature of about $-40°$ C. there is a rapid increase in the number of active nuclei. If this is correct the temperature at the base of cirrus may tend toward this value. Thus, the distribution of mean cirrus-base temperatures versus height may differ significantly from normal temperature-height distributions and it would be feasible to use cirrus-base temperature-height curves to estimate or forecast the base of cirrus cloud. Appleman [1] suggested the use of his con-
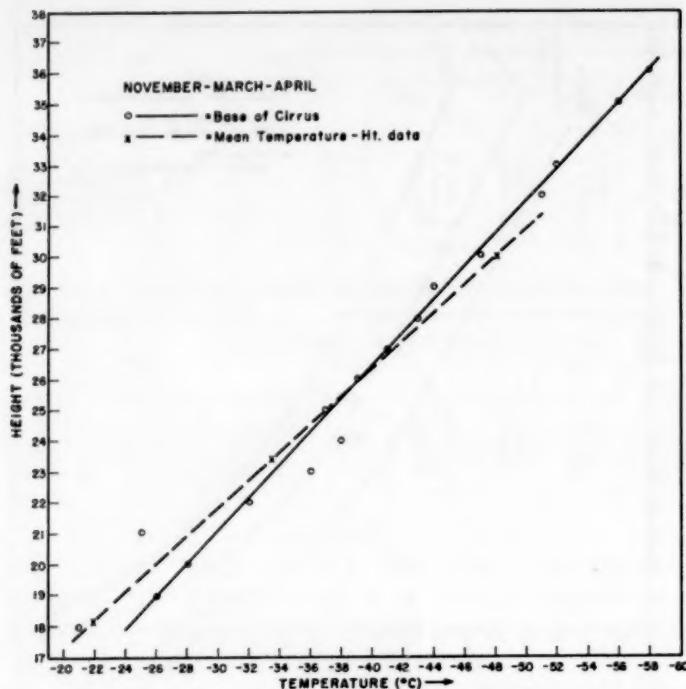
FIGURE 2.—Comparison between temperature-height distribution of base of cirrus and mean temperature-height data for all days in November, March, and April.

FIGURE 3.—Ogive giving cumulative percentage occurrence of cirrus versus temperature of cirrus base.

trail forecasting curves for this purpose. These curves are approximately in the proper temperature range and thus could prove useful in this connection although, on the average, they would necessarily give larger errors than mean cirrus-base temperature-height curves.

In order to investigate the feasibility of this technique, curves were drawn giving the mean temperatures at the base of cirriform cloud versus height for four groups of months. Mean temperature-height data [6] were used to draw comparison curves. The results for November-March-April are typical and these are shown in figure 2. These curves indicate that the temperature-height distribution of the base of cirrus is not sufficiently abnormal

to be of much practical use. However, the temperatures at which the curves intersect are of some theoretical interest and these are listed in table 7. The intersections are somewhat ambiguous so that the results are only approximate. Table 7, however, indicates that the temperatures at the base of cirrus are somewhat closer to −40° C. in the mean than is normal for the given height.

Even though cirrus-cloud bases are found over a near-normal temperature range it is possible that a high proportion of cirrus forms with its base near −40° C. and is

TABLE 7.—*Intersections of cirrus-base temperature-height curves with normal temperature-height curves*

Season	Temperature (°C.)
Dec-Jan-Feb	−40
Nov-Mar-Apr	−39
May-Sept-Oct	−43
June-July-Aug	−37
Mean	−40

TABLE 8.—*Base temperatures associated with maximum occurrence of cirrus*

Season	Temperature range (°C.)
Dec-Jan-Feb	−37 to −42
Nov-Mar-Apr	−40 to −45
May-Sept-Oct	−40 to −44
June-July-Aug	−28 to −33
Mean	−39

TABLE 9.—*Distribution of tropopause-cirrus tops separation*

(a) According to Seasons

Tropopause minus cirrus tops (1000's of ft.)	Warm months (%)	Intermediate months (%)	Cold months (%)	Year (%)
−5.0>	2	1	1	1
−5.0 to −2.1	2	3	2	2
−2.0 to −0.1	7	6	15	9
0 to +2.0	22	19	27	22
+2.1 to +5.0	31	27	24	27
+5.1 to +10.0	24	28	26	26
>+10.0	12	17	4	11
Mean (1000's of ft.)	4.5	5.4	3.4	4.4

(b) According to Cirrus Amounts

Tropopause minus cirrus tops (1000's of ft.)	Overcast (%)	Broken (%)	Scattered (%)	Mean (%)
−5.0>	0	2	1	1
−5.0 to −2.1	2	0	4	2
−2.0 to −0.1	16	10	5	10
0 to +2.0	32	19	18	23
+2.1 to +5.0	25	31	30	29
+5.1 to +10.0	21	25	24	23
>+10.0	4	12	18	12
Mean (1000's of ft.)	3.1	4.6	5.4	4.4

TABLE 10.—*Stratospheric cirrus (heights in thousands of feet)*

	Month	Base	Top	Tropopause	Base minus tropopause	Top minus tropopause	Cloud amount	Tropospheric airmass
1	Jan.	30.0	35.0	30.6	−0.6	4.1	Scattered	maritime Polar
2	Jan.	32.0		30.5	1.5		Scattered	maritime Arctic
3	Jan.	20.0	38.0	36.0	−16.0	2.0	Overcast	maritime Polar
4	Feb.	35.0	38.0	35.5	−0.5	2.5	Scattered	maritime Arctic
5	Mar.	34.0	39.0	35.6	−1.6	3.4	Scattered to broken.	maritime Polar
6	Mar.		38.0	36.0		2.0	Overcast	maritime Polar
7	Apr.	45.5	48.0	27.0	18.7	21.5	Overcast	maritime Arctic
8	Apr.	33.0	34.0	29.0	4.0	5.0	Scattered	maritime Arctic
9	July	37.0	39.0	32.5	4.5	6.5	Broken	maritime Polar
10	Aug.	20.0	36.0	32.5	−12.5	3.5	Broken	maritime Polar
11	Sept.	38.0	42.0	36.7	1.3	5.3		maritime Tropical
12	Sept.	21.0	40.0	37.0	−16.0	3.0	Overcast	maritime Polar
13	Oct.	35.0	36.0	31.0	4.0	5.0	Scattered	maritime Polar
14	Oct.	35.0		33.5	1.5		Scattered	maritime Polar
15	Oct.	40.0		30.5	9.5		Scattered	maritime Polar
16	Oct.	41.0	42.0	34.0	7.0	8.0	Broken	maritime Polar
17	Nov.	33.0	38.0	34.8	−1.8	3.2	Scattered	maritime Polar
18	Nov.	20.0	39.5	37.5	−17.5	2.0	Scattered	maritime Polar
19	Dec.	31.0	31.0	25.5	5.5	5.5	Scattered	maritime Arctic

TABLE 11.—*Visibility in cirriform cloud*

Visibility less than	1 mile	½ mile	¼ mile
Percentage	70	60	30

then advected across the thermal field. Under such circumstances there would tend to be a maximum of occurrence of cirrus whose base temperature is in the vicinity of −40° C. Ogives were drawn giving cumulative cirrus occurrence versus temperature of cloud base to see whether a maximum in slope existed near −40° C. Figure 3 gives the ogive for November-March-April. This curve is typical and reveals a weak maximum in its slope between −40° C. and −45° C. Similar results were obtained for the other curves and these are listed in table 8. These results imply a small tendency for the base of cirrus to be found with increased frequency in the vicinity of −40° C.

From the ogive curves it can be deduced that 70 percent or more of cirrus layers for a given season lie with their bases within a 10,000-ft. range. The Project Cloud Trail Report [7] indicates even higher percentages. Thus an estimate of the cloud base at a mean position should give an average accuracy of close to 3,000 ft. As a result, any curves which give estimates in the vicinity of mean base heights should give similar accuracy.

10. TOPS OF CIRRUS LAYERS AND THE TROPOPAUSE

An analysis was carried out to see whether there was any significant relationship between the tops of cirrus layers and the tropopause. The results of this analysis are summarized in table 9 and these indicate that the separation between the tropopause and cloud tops varies a good deal but is least in the cold months and with overcast layers. French and Johannessen [8] found a somewhat closer relationship between cirrus tops and the tropopause.

11. STRATOSPHERIC CIRRUS

From table 9 it is apparent that cirrus is largely confined to the troposphere. However, in view of the interest in stratospheric humidity, those cases which penetrated at least 2,000 ft. into the stratosphere were investigated. Approximately 5 percent of the cases fell into this category and the pertinent data on these are given in table 10. Owing to the errors involved, a few of these instances may be, in actuality, tropospheric cloud but for the most part the reports seem to be authentic stratospheric cirrus. Most of the cases involved scattered cloud in the lower stratosphere above maritime Polar tropopause. Thus, some of this cloud may have formed in tropical tropospheric air which was absorbed into the stratosphere through a break or fold in the tropopause.

12. VISIBILITY IN CIRRUS CLOUD

Approximately 40 reports were obtained of visibility in cirriform cloud. Many of these reports were only rough estimates so that the results of this analysis (table 11) can be depended upon to give only an order of magnitude.

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A POSSIBLE SINGULARITY IN THE JANUARY MINIMUM TEMPERATURE AT PHOENIX, ARIZONA

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ABSTRACT

Daily minimum temperature averages for the Phoenix City Office based on 61 years of record show a definite rise in the period January 9–17, with relatively lower values in the 9-day periods preceding and following. This rise is investigated statistically and shown to be greater than chance would allow if random effects alone are responsible for the phenomenon. The possibility of a relationship between the Phoenix singularity and those demonstrated by Wahl [1] for stations in the eastern United States is discussed briefly.

1. INTRODUCTION

Evidence presented by Wahl [1] indicates the strong possibility that a period of warming has occurred between the 20th and 23d of January at stations along the northeastern coast of the United States over a period of about 75 years ending in 1952. Using unsmoothed daily mean temperature records for Washington, D. C., New York City, Boston, Mass., and Blue Hill Observatory, Mass., Wahl showed that a slight rise in temperature occurred during the period January 20–23 at all four stations. Columbia, Mo., farther to the west, also showed a rise but some days earlier (January 17–21). An inspection of the records for Phoenix, Ariz. indicates that a similar phenomenon has occurred here, but somewhat earlier in the month than at Columbia, Mo.

The phenomenon first became evident in the Phoenix records in a table designed to show the climatological expectancy that "severe freezing conditions" will persist for a given number of hours during each week of the winter season in the Salt River Valley—a question of considerable interest to Valley citrus growers. Table 1 shows the total number of hourly observations which reported "severe freezing conditions" and which were followed by at least N more consecutive hourly observations with "severe freezing conditions" during each week in December, January, and February. The following criteria for temperature T establish the definition of "severe freezing conditions" that was used:

        1948–1955 (Airport record): $T \lessgtr 28°$ F.
        1916–1947 (City Office record): $T \lessgtr 30°$ F.

A temperature of 28° or less was used as a criterion at the Airport because minimum temperatures at other Valley stations average as much as 10° lower than airport temperatures, giving severe freezing conditions in important agricultural areas when temperatures are only a few degrees below freezing at the Airport. In combining the two records, 30° was used at the City Office because 3 years of overlapping record showed that very low temperatures average about 2° higher there than at the Airport during the winter months. The numerical value of the temperatures used at each location in combining the records is not extremely critical in this case because we are essentially interested in the seasonal distribution of runs of various lengths of low temperatures, and one would expect the distribution to look about the same for temperatures within a range of several degrees of any given temperature.

Table 1 shows considerably lower frequencies during the week January 12–18 than in either the preceding or following week, and indicates that very low temperatures are less frequent during that week. Accordingly, an inspection was made of daily minimum temperature averages at the City Office for the entire period of record (1895–1956) and a decided rise in mean minimum temperature was indicated during the period January 9–17 (fig. 1).

TABLE 1.—*Total number of hourly observations which had "severe freezing conditions" and which were followed by at least N more consecutive hourly observations with "severe freezing conditions." Data under column $N=0$ are the total number of hourly observations during the 40-year period with "severe freezing conditions." Definition of "severe freezing conditions": 1948–55 (Airport): $T \lessgtr 28°$ F., 1916–47 (City Office): $T \lessgtr 30°$ F.*

Week	N											
	0	1	2	3	4	5	6	7	8	9	10	11
Dec. 1–7	8	3	2	1								
Dec. 8–14	62	42	28	19	12	7	3	1				
Dec. 15–21	52	25	11	5	2	1						
Dec. 22–28	62	31	20	12	5	2	1					
Dec. 29–Jan. 4	86	58	39	27	20	15	10	5	2		5	2
Jan. 5–11	74	54	42	31	25	20	17	14	11	8	5	2
Jan. 12–18	25	11	5	3	1							
Jan. 19–25	122	88	65	48	34	23	17	13	9	5	3	1
Jan. 26–Feb. 1	36	21	12	6	3	1						
Feb. 2–8	24	12	7	4	2	1						
Feb. 9–15	35	21	13	6	2							
Feb. 16–22	5	2	1									
Feb. 23–Mar. 1	0											
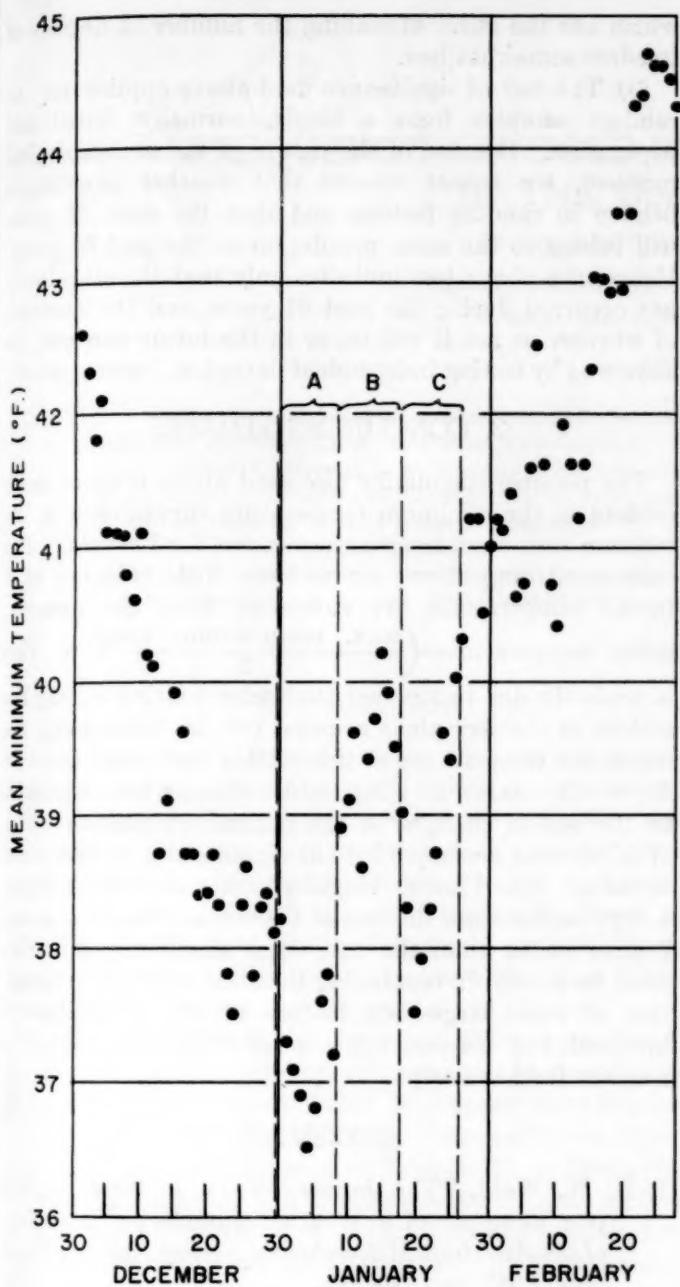
FIGURE 1.—Mean daily minimum temperature. City Office, Phoenix, Arizona (December 1895–February 1956).

2. STATISTICAL INVESTIGATION

Before we can investigate this possible singularity statistically, we must set up a working definition of a "singularity." For the purposes of this discussion we define a singularity as a period of higher or lower values of an element, that is superimposed on the seasonal trend curve of the element, and that exhibits a strong tendency to recur at about the same time each year. If we accept the official U. S. Weather Bureau normal daily minimum temperatures [2] as a "best estimate" of the smoothed seasonal trend of this element during the period of interest, we can investigate statistically the question of whether or not we have a singularity in terms of our definition.

The following procedure was used. The 9-day period in question (January 9–17) was bracketed by two other 9-day periods (December 31–January 8, and January 18–26) and average values in each year during each of these three 9-day periods were computed using daily minimum temperature data for the City Office for December 1895 through February 1956. These average values were used instead of individual daily values to minimize the effects of serial correlation in the data. One approach might be to compute the mean minimum temperatures during the three periods for the entire length of record, then compare them statistically by using Student's "t" test on the final averages. Throughout the period of record of the City Office, however, the instruments have been exposed at a number of different locations and elevations, making the entire series of observations non-homogeneous. The instrument exposures during the three periods in *each individual year* are comparable, however, so the method of "pairing" was used. Hypotheses are harder to prove (or disprove) by this method than by averaging the whole series, because the number of degrees of freedom in the estimate of the variance is reduced by about one-half; however, the nature of the data in this problem forces us to pair the observations.

Let us call the period December 31–January 8 "period A," the period January 9–17 "period B," and the period January 18–26 "period C;" and call the *observed* average minimum temperature in the ith year in periods A, B, and C, respectively, T_{ai}, T_{bi}, and T_{ci}. As a first step, averages during each year for periods A and B were paired and the algebraic difference $T_{bi} - T_{ai}$ computed, and a list of differences was made for all years. Similarly for periods B and C, differences $T_{bi} - T_{ci}$ were computed and listed for all years.

Table 2 shows the official U. S. Weather Bureau normal daily minimum temperatures at the Phoenix City Office throughout the three 9-day periods in question. Let us call $\overline{T}_a$, $\overline{T}_b$, and $\overline{T}_c$ the average of the *normal* mean minimum temperatures in periods A, B, and C, respectively. Then,

$$\overline{T}_a = 38.00, \quad \overline{T}_b = 37.67, \quad \overline{T}_c = 38.33$$

and,

$$\overline{T}_b - \overline{T}_a = -0.33, \quad \overline{T}_b - \overline{T}_c = -0.66$$

On the basis of these differences in the average of *normal* values, we would expect the *observed* average minimum temperatures T_{ai}, T_{bi}, and T_{ci}, in the ith year in periods A, B, and C, respectively, to satisfy the following hypotheses:

$$\lim_{n \to \infty} \left[\frac{\sum_{i=1}^{n}(T_{bi} - T_{ai})}{n} \right] \to -0.33$$

$$\lim_{n \to \infty} \left[\frac{\sum_{i=1}^{n}(T_{bi} - T_{ci})}{n} \right] \to -0.66$$

These hypotheses can be tested using Student's "t" test

by testing the equivalent hypotheses:

$$\frac{\sum_{i=1}^{n} T_{bi}}{n} - \frac{\sum_{i=1}^{n} T_{ai}}{n} + 0.33 = 0$$

and

$$\frac{\sum_{i=1}^{n} T_{bi}}{n} - \frac{\sum_{i=1}^{n} T_{ci}}{n} + 0.66 = 0$$

for $n=61$, allowing $n-1$ degrees of freedom. In this case, if both hypotheses are rejected, we will have good reason to believe that the average minimum temperature is higher or lower in period B than one would expect it to be due to chance variations from the smoothed seasonal trend. Choosing a 5 percent level of significance, we reject the hypotheses if $t < -2.00$ or if $t > +2.00$.

The value of t for the set of differences between B and A values is $+3.45$, while that for the differences between B and C values is $+2.30$, indicating a strong probability that the minimum temperature values in period B are higher than one would expect them to be due to chance variations alone.

The following points should be emphasized about the above statistical treatment:

(1) The significance test was applied after inspecting the data and this selection increases the probability of getting a high value of t.

(2) The number of degrees of freedom was determined on the assumption that the years are independent. This is not strictly true because of year-to-year persistence, which has the effect of making the number of degrees of freedom somewhat less.

(3) The test of significance used above applies only to random samples from a single, normally distributed population. Because of the nature of the meteorological problem, we cannot assume that weather phenomena behave in random fashion and that the next 61 years will belong to the same population as the past 61 years. Hence, the above test indicates only that the singularity has occurred during the past 61 years, and the question of whether or not it will occur in the future can only be answered by testing independent data; i. e., future records.

3. CONCLUDING REMARKS

The possible singularity discussed above is much more evident in the minimum temperature curves than in the mean or maximum temperature curves for Phoenix. The maximum temperature curves show little evidence of it (mean temperatures are computed from the formula:

$$\text{mean temperature} = \left(\frac{\text{max. temp.} + \text{min. temp.}}{2}\right).$$

This is probably due to the fact that solar heating during the middle of the day plays a major role in determining the maximum temperature at this station and tends to make day-to-day maximum temperature changes less responsive to the subtle changes in the general circulation which Wahl showed accompanied the singularities at east coast stations. The Phoenix singularity has occurred roughly 4 days earlier than the one at Columbia, Mo., and about 7 days earlier than the east coast singularity [1]. One must be careful in concluding that the eastward propagation of some large-scale feature of the atmosphere is involved, but the possibility seems interesting enough to warrant further study.

REFERENCES

1. E. W. Wahl, "The January Thaw in New England (An Example of a Weather Singularity)", *Bulletin of the American Meteorological Society*, vol. 33, No. 9, Nov. 1952, pp. 380–386.
2. U. S. Weather Bureau, *Daily Temperature, Degree Day, and Precipitation Normals, Phoenix, Arizona CO,* (Based on, or adjusted to, the 1921–1950 period), Washington, D. C.

TABLE 2.—*Normal daily minimum temperature. City Office, Phoenix, Ariz.* [2]

Date	Normal minimum (° F.)	Date	Normal minimum (° F.)
Dec. 31	39	Jan. 14	38
Jan. 1	38	15	38
2	38	16	38
3	38	17	38
4	38	18	38
5	38	19	38
6	38	20	38
7	38	21	38
8	37	22	38
9	37	23	38
10	37	24	39
11	37	25	39
12	38	26	39
13	38		

FREQUENCY OF COLD-WET CLIMATIC CONDITIONS IN THE UNITED STATES [1]

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ABSTRACT

Cold-wet conditions occur most frequently in the extreme Pacific Northwest, with a second maximum in the Northeast from the Great Lakes to northern New England. The minimum occurrence is in the southern portions of Arizona and adjacent California, New Mexico, Texas, and Florida. During the colder part of the year (from October through April), cold-wet conditions occur over 50 percent of the time in the two above-mentioned regions of maximum incidence, reaching 70 to 80 percent in January.

In summer (July and August), cold-wet conditions occur less than 10 percent of the time except in the far northeastern and Lake States and on the north Pacific coast. The Olympic Peninsula of Washington has more than 30 percent frequency all summer, the highest in the country during this season.

1. INTRODUCTION

One of the most disagreeable types of weather is a combination of coldness and wetness. Such a combination calls for the development and use of special clothing and footwear to keep the body warm and dry, not only for comfort but for protection against lowered resistance associated with chill and against ever-present danger of trench foot. The problem is of universal concern, but is particularly serious for people spending much time in the open, such as farmers, loggers, police, and soldiers.

In view of the human significance of cold-wet conditions, to say nothing of their importance as a widespread and distinctive type of environment, it is desirable to inquire into the frequency with which they occur in different areas. Many previous authors, such as Köppen [1], de Martonne [2], and Thornthwaite [3], have developed climatic indices based upon combinations of temperature and rainfall, but these indices have dealt chiefly with monthly mean values, primarily for agricultural, ecologic, or geographic purposes. The cold-wet that affects an individual is not a mean, but a simultaneous occurrence of coldness and wetness at a given instant. Furthermore, precipitation is only one aspect of wetness; muddy ground, puddles, and slush represent another aspect. Similarly, low air temperature is only one factor contributing to coolness; wind and lack of sunshine are others.

The analysis of the natural frequency of occurrence of simultaneous combinations constituting cold-wet conditions has apparently not been attempted heretofore, and has in fact become feasible only because of the possibility of machine-analysis of masses of hourly data.

2. DEFINITION OF COLD-WET

A thoroughly miserable cold-wet type of weather would include temperature hovering just above freezing, falling rain driven by a penetrating wind, and muddy, slushy ground. To decide exactly what quantitative combinations and limits should be included in the concept of cold-wet, and to translate these values into quantities that can be processed with existing punch-card data, is a matter requiring rather delicate judgment. Selection of cold-wet climatic criteria, as used in this report, is based on: (1) studies conducted in the field and laboratory by physiologists and biophysicists of the Quartermaster Corps; (2) experience of other individuals living in the field and conducting tests under cold-wet conditions; (3) study of climatic conditions as they occur at typical cold-wet places on the earth, such as the Aleutian Islands; (4) examination and study of available literature, much of it based upon research by scientists of the Quartermaster Corps over a period of more than ten years; and (5) a study performed by the Weather Bureau for the Quartermaster Corps using data from selected stations in the United States and Alaska, resulting in the adoption of the criteria to be used in this report.

The four mutually exclusive combinations of cold-wet conditions selected for use in this report are as follows:

A. Observations with falling precipitation or fog at the time of observation, with temperatures from 23° F. through 59° F.

B. Observations with falling precipitation or fog at the time of observation, with temperatures from 60° F. through 67° F. and wind of 5 m. p. h. or more.

C. Observations with no falling precipitation or fog at time of observation, with snow on ground, and with temperatures from 23° F. through 49° F.

FIGURE 1.—Location of the 61 stations used in the study.

D. Observations with no falling precipitation or fog at the time of observation, with no snow on ground, with 6–10 tenths clouds, and with temperatures from 23° F. through 49° F.

True cold-wet conditions cannot be defined by any one meteorological element, but rather result from two or more elements in combination. For example, snow on the ground cannot be considered as indicative of cold-wet conditions unless accompanied part of the time by air temperatures near or above freezing. The Arctic and Subarctic have snow on the ground much of the winter, but, since winter temperatures usually remain well below freezing in these regions, cold-dry rather than cold-wet conditions prevail, with quite different problems.

Certain weather elements directly associated with cold-wet conditions are not included in the criteria because they were not available on punched cards. Two of the more important of these missing elements are radiation and relative humidity. An attempt has been made to compensate for this deficiency by including falling precipitation and cloudiness in the criteria. High relative humidities and low radiation values are usually associated with these elements.

In considering the criteria presented above, it should be emphasized that they define cold-wet only in terms of *climate;* given criteria may or may not have application to specific physiological or biophysical problems involving the reaction of man to this climate. All the criteria have a bearing on some aspect of outdoor activities and needs for clothing and footwear protection.

3. DATA

Hourly data used in preparing this study were compiled by personnel of the U. S. Weather Bureau for 61 broadly representative stations (fig. 1) in the United States, in accordance with the above criteria provided by the Environmental Protection Research Division, Quartermaster Research and Development Command. Tabulation was performed at the National Weather Records Center, Asheville, N. C. using data available on punched cards. The period of record was limited to five years (July 1948 through June 1953) since observations for "state of ground," required in determining the existence of a snow cover, were not available for the years prior to 1948.

The 5-year period of record used in this study includes approximately 43,000 hourly observations for each station, a sample large enough to provide a representative picture of the situation at the stations and a generalized picture for the country.

State of ground, reported every 6 hours at U. S. Weather Bureau stations, was used to determine the presence or absence of a snow cover. If a 6-hourly observation showed "snow-on-ground" in an amount greater than a trace, it was considered that the succeeding five hourly observations also had snow-on-ground. If no snow was on the ground at the time of the 6-hourly observation, the succeeding five hourly observations were considered to have no snow-on-ground, except that if falling snow was reported on two consecutive hourly observations, the second and remaining observations within the 6-hour period were also considered as having snow on the ground.

Data were used only from lowlands and scattered stations in interior plateaus. No attempt is made to analyze mountain conditions since they vary considerably with slight differences in location, and data from mountains are inadequate. Latitude, slope, altitude, exposure, and other factors strongly influence the climate in mountains, including the distribution and frequency of cold-wet conditions. In general, it may be expected that cold-wet conditions will occur earlier in fall and will last later in spring in mountains than in adjacent lowlands. At high altitudes in some of the mountains of the western part of the country these conditions may persist throughout the summer. During winter, at moderate to high altitudes, temperatures are usually below 23° F., and cold-dry rather than cold-wet conditions occur.

4. MONTHLY FREQUENCIES

The total frequency of occurrence (in percent) of all four criteria combined, for each of the 61 stations used, for each month of the year, is given in table 1, together with the average percent per month on an annual and October–April basis.

Figures 2 through 13 were designed to show the broad geographical and seasonal differences of cold-wet conditions in the United States. The point values of table 1 were plotted on monthly maps, and isarithms were interpolated at intervals of 10 percent frequency. The isarithms are not sharp lines of discontinuity between regions, but represent values in a gradual transition between greater and lesser frequencies. The result is a generalized picture of conditions in the lowland and plateau areas that constitute the greater part of the United States.

SEPTEMBER THROUGH APRIL

The greatest frequency and extent of cold-wet conditions in the United States occurs during the period from October through April. For purposes of discussion,

Table 1.—*Percent frequency of occurrence of cold-wet conditions at stations in the United States.* (Period of record 1948–1953.)

Station	Monthly percent												Average percent per month	
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Oct.-Apr.
Phoenix, Ariz	18.5	10.5	7.4	2.7	0.5	0.0	0.0	0.0	0.1	1.0	4.1	13.7	4.9	8.3
Yuma, Ariz	10.2	3.4	2.2	.6	.1	.0	.0	.0	.0	.6	1.7	7.3	2.2	2.2
Little Rock, Ark	47.0	37.1	29.4	12.7	7.5	.5	.1	.1	3.5	10.0	23.8	40.7	17.7	28.7
Texarkana, Ark	38.1	32.6	22.8	10.9	6.1	.7	.0	.1	2.3	7.2	21.0	35.9	14.8	24.1
Fresno, Calif	49.5	31.7	23.7	7.1	2.2	.3	.0	.0	.6	3.9	24.5	59.6	16.9	28.6
Sacramento, Calif	51.0	34.1	25.8	9.3	3.8	.9	.1	.1	.9	6.7	25.0	58.9	18.1	30.1
San Diego, Calif	20.1	18.4	9.4	9.2	4.5	2.6	3.4	2.6	5.5	9.2	14.5	16.1	9.6	13.8
San Francisco, Calif	41.5	34.0	24.3	14.9	8.5	7.1	6.0	7.8	5.9	11.5	20.5	37.8	18.3	26.4
Denver, Colo	29.2	39.6	41.1	40.1	24.5	9.1	3.0	2.2	7.4	18.3	32.5	38.5	23.8	34.2
Washington, D. C	56.7	51.2	43.4	27.2	15.2	4.7	.0	.7	7.0	15.2	38.1	55.1	26.2	41.0
Jacksonville, Fla	15.9	17.6	9.5	3.9	.8	.1	.0	.0	.2	2.9	10.0	21.0	6.8	9.0
Miami, Fla	1.0	3.3	.8	1.0	.1	.0	.0	.0	.0	.1	.8	1.6	.7	1.2
Atlanta, Ga	38.9	35.3	31.7	14.1	4.2	.7	.2	1.4	4.7	12.9	28.4	50.2	18.6	30.2
Boise, Idaho	56.7	59.0	59.9	23.4	16.5	7.3	.2	.7	4.3	19.5	50.3	74.9	31.1	49.1
Pocatello, Idaho	50.3	51.7	59.8	27.3	25.0	8.3	.6	.9	6.4	24.8	53.2	64.3	31.0	47.3
Chicago, Ill	59.0	61.5	59.6	47.3	16.6	4.4	2.2	3.8	7.5	20.7	54.3	51.5	32.4	50.6
Des Moines, Iowa	38.6	56.2	57.8	43.2	16.1	6.9	2.4	4.8	6.8	16.3	38.1	43.5	27.6	42.0
Goodland, Kans	28.6	33.9	40.0	36.5	22.0	8.3	5.4	6.9	10.7	17.7	34.5	34.5	23.2	32.2
Wichita, Kans	33.7	42.6	38.5	26.9	10.8	3.6	1.6	2.2	6.3	9.8	28.6	37.7	20.2	31.1
Louisville, Ky	63.1	52.9	46.0	32.5	12.8	2.6	.5	1.5	6.6	18.8	42.2	54.6	27.8	44.3
New Orleans, La	18.3	22.2	14.2	6.9	.8	.0	.0	.0	.0	2.8	13.9	24.3	8.6	14.7
Caribou, Maine	30.3	27.4	61.1	74.6	37.8	19.7	10.8	14.7	26.2	52.2	70.0	42.8	39.0	51.2
Portland, Maine	57.2	52.9	65.8	54.3	34.8	16.7	8.2	13.4	20.5	36.5	59.2	51.5	39.2	53.9
Boston, Mass	64.0	65.6	61.9	45.8	29.1	7.7	4.8	5.6	9.4	21.3	46.6	51.9	34.5	51.0
Calumet, Mich	26.9	31.4	49.8	69.8	39.4	21.2	11.5	12.4	26.3	52.9	70.3	40.7	37.7	48.8
Sault Ste. Marie, Mich	38.7	38.2	58.9	57.6	35.7	22.6	14.5	18.4	32.5	57.1	77.6	54.1	42.2	54.6
Duluth, Minn	17.3	26.5	49.6	67.2	39.0	20.5	15.9	14.1	28.6	48.1	56.1	30.7	34.5	42.2
Minneapolis, Minn	25.9	44.9	58.3	50.0	18.6	7.6	3.4	6.0	12.6	26.8	50.8	36.1	28.4	41.8
Kansas City, Mo	41.0	49.3	46.9	32.4	10.0	2.6	1.7	1.6	5.9	13.3	32.9	44.0	23.5	37.1
St. Louis, Mo	53.7	52.5	46.0	33.5	9.6	2.3	.7	1.4	6.4	15.4	40.1	52.0	26.1	41.9
Billings, Mont	37.9	56.8	45.5	39.3	24.9	14.4	4.1	3.4	17.3	31.5	50.0	50.1	31.3	44.4
Great Falls, Mont	40.9	50.5	48.4	40.0	29.5	19.5	5.4	5.7	18.7	30.4	52.1	47.9	32.4	44.3
Grand Island, Nebr	36.8	45.7	47.6	39.9	17.8	6.3	4.5	4.5	7.6	18.5	40.2	40.5	25.8	38.5
Elko, Nev	47.4	46.2	56.0	32.0	24.1	7.5	1.5	.9	6.6	21.0	39.6	53.5	28.0	42.2
Las Vegas, Nev	34.9	18.2	13.4	2.7	1.1	.4	.0	.0	.3	1.7	9.2	25.9	9.0	15.1
Reno, Nev	47.0	39.9	44.0	21.0	16.4	4.6	.5	1.2	5.6	13.6	26.0	50.5	22.5	34.6
New York City, N. Y	63.6	53.4	55.1	35.1	21.4	6.7	1.5	.9	5.1	12.6	37.8	54.0	28.9	44.5
Syracuse, N. Y	65.4	65.3	65.5	53.8	24.4	6.5	3.3	6.3	18.2	39.5	67.3	64.2	40.0	60.1
Asheville, N. C	50.1	43.1	39.6	25.3	13.3	5.8	3.4	8.3	20.9	29.7	38.1	49.2	27.2	39.3
Raleigh, N. C	37.6	39.6	29.0	15.7	8.0	3.1	.6	1.1	5.1	14.8	25.5	42.7	18.6	29.3
Bismarck, N. Dak	11.0	25.6	44.7	48.0	26.0	11.5	3.9	5.8	15.6	35.0	40.0	21.6	24.1	32.3
Fargo, N. Dak	8.9	27.2	49.7	47.8	23.6	9.6	4.2	6.0	13.7	35.0	46.8	23.8	24.7	34.2
Cleveland, Ohio	68.1	64.3	65.3	51.2	17.4	4.6	2.3	3.7	9.2	27.1	60.9	61.9	36.3	57.0
Dayton, Ohio	69.9	62.7	58.2	45.2	16.7	5.6	1.0	4.1	9.9	26.1	55.4	58.8	34.5	53.8
Oklahoma City, Okla	34.2	38.9	27.0	18.5	9.3	1.6	.7	.5	3.1	8.1	21.4	32.6	16.3	25.8
Medford, Oreg	77.4	67.9	58.9	28.0	23.6	9.3	.7	.6	5.8	29.1	61.4	83.9	37.2	58.1
Portland, Oreg	74.5	75.2	74.6	36.2	23.4	11.7	3.2	3.0	15.1	43.2	69.3	83.3	42.7	65.2
Harrisburg, Pa	70.2	60.6	55.5	39.8	18.8	5.4	1.0	1.3	10.1	23.8	54.6	65.4	33.9	52.8
Charleston, S. C	23.3	23.0	18.5	8.6	2.3	.2	.0	.1	2.4	9.1	14.6	33.6	11.3	18.7
Huron, S. Dak	19.7	40.8	51.5	44.8	23.0	7.7	2.9	4.5	10.8	27.8	40.4	27.1	25.1	36.0
Rapid City, S. Dak	30.3	40.0	45.0	42.7	27.2	10.4	4.6	4.3	12.3	27.0	39.7	33.7	26.4	36.9
Nashville, Tenn	53.6	46.0	36.4	23.2	6.3	1.6	.1	.7	3.9	15.4	35.2	48.0	22.5	36.8
Amarillo, Tex	27.7	30.0	25.4	18.6	11.4	3.4	2.3	3.4	6.5	7.9	20.8	28.6	15.5	22.7
Brownsville, Tex	14.4	13.2	7.4	1.4	.6	.0	.0	.0	.0	1.6	5.5	10.8	4.6	7.8
El Paso, Tex	22.5	14.9	8.4	5.3	1.0	.3	.7	.4	1.1	2.6	10.2	18.9	7.2	11.8
Houston, Tex	27.9	29.1	12.7	8.3	3.3	.2	.0	.1	.1	6.3	19.0	25.6	11.0	18.4
Salt Lake City, Utah	51.3	47.7	54.2	23.3	16.5	3.9	.5	.7	3.4	17.1	45.0	71.4	27.9	44.3
Spokane, Wash	55.5	69.1	65.2	34.1	20.2	13.1	2.7	2.3	8.8	39.0	70.3	70.3	37.6	57.6
Tatoosh, Wash	81.8	80.3	80.3	66.1	40.9	32.3	32.3	34.7	33.7	39.8	66.5	82.1	55.9	71.0
Cheyenne, Wyo	34.5	47.8	43.0	40.4	37.1	16.9	6.4	5.9	17.0	25.0	38.3	42.8	29.6	38.8
Sheridan, Wyo	35.7	52.5	49.8	42.1	27.7	13.2	5.5	3.1	15.9	32.2	48.7	42.2	30.7	43.3

September is included in this period, for during this month the frequency and extent of cold-wet conditions first begin to increase throughout the country after the relatively infrequent occurrence during summer. The frequency of cold-wet conditions does not increase to a winter maximum in all parts of the country and then decrease in spring; the winter maximum occurs in some parts of the country, but in areas such as the North Central States midwinter is too cold to be wet.

In September (fig. 2) only the Appalachian area and the extreme northern part of the United States, especially the northwestern part of Washington, show frequencies of cold-wet conditions of 20 percent or greater. Most of the United States has less than 10 percent occurrence during this month.

During October (fig. 3) there is a considerable increase (over September) in cold-wet conditions in the northern part of the country, especially in New England and in the vicinity of the Great Lakes where increases of about 20 percent occur. During this month approximately the northern quarter of the country has cold-wet conditions at least 30 percent of the time. In the extreme northern part of the Great Lakes area (represented by Calumet and Sault Ste. Marie, Mich.) and in Caribou, Maine, these conditions occur over 50 percent of the time; secondary centers occur in the extreme Northwest (Tatoosh Island, Wash., and Portland, Oreg.) and in the Appalachian area as far south as North Carolina. The southern part of the country has cold-wet conditions less than 10 percent of the time, with Miami, Fla., recording less than 1 percent.

FIGURE 2.—Frequency (percent) of cold-wet conditions during September.

FIGURE 4.—Frequency (percent) of cold-wet conditions during November.

FIGURE 3.—Frequency (percent of cold-wet conditions during October.
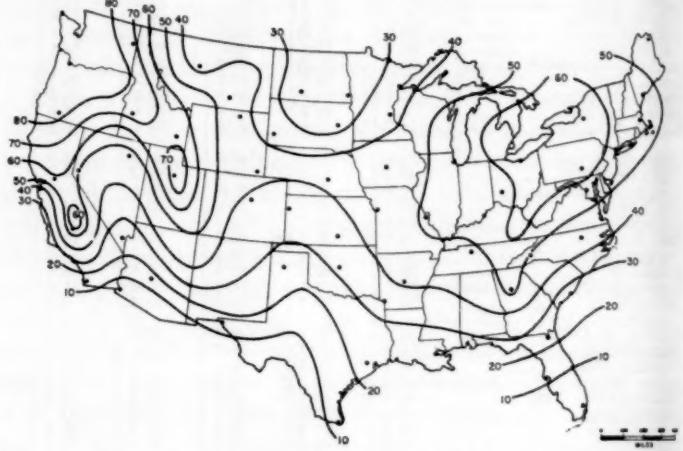
FIGURE 5.—Frequency (percent) of cold-wet conditions during December.

The sudden increase that occurs from September to October continues into the month of November (fig. 4). Northeastern United States, the Great Lakes areas, and the Pacific Northwest have cold-wet conditions from 50 to over 70 percent of the time. The southern part of the country shows increases of between 20 to 30 percent, and only the southern portions of Florida, Texas, and Arizona, and southeastern California have cold-wet less than 10 percent of the time.

Only a slight rise (10 to 15 percent) occurs in the north central part of the country, owing to the increase of very cold weather during this month.

In December (fig. 5), cold-wet frequencies actually decrease in the northern part of the country, except in the Pacific Northwest. The greatest increases occur in California and at the intermontane stations of the western United States where cold-wet conditions occur as far south as northern Arizona and New Mexico as much as 30 to 40 percent of the time.

In the north central part of the country the pronounced influence of very cold weather is now evident. Marked decreases in cold-wet frequency, of the order of 15 to 25

percent, occur in Minnesota, North and South Dakota, and parts of adjoining States. During January and February, these States are dominated by very cold, dry, polar continental air which has its source in interior, snow-covered Canada. Temperatures are usually much too low for cold-wet conditions to occur. The decrease also occurs in northern Maine, and to a lesser extent, near the Great Lakes. To the south, slight increases of about 5 to 10 percent are noted in Texas, Oklahoma, Kansas, Colorado, and Nebraska. In these States the frequency of cold-wet conditions is probably limited by weather that is either too warm, too dry, or too cold.

The increased frequency of cold-wet conditions is particularly noticeable in the far western part of the country—California, Oregon, and Washington—where the winter rains, accompanied by cloudiness and lower temperatures, now prevail. In central and northern California these conditions occur 60 to over 80 percent of the time in December. Of considerable interest is the fact that the frequency in central and northern California is comparable to that of the Great Lakes and New England. Southern Florida, with 2 percent at Miami, con-
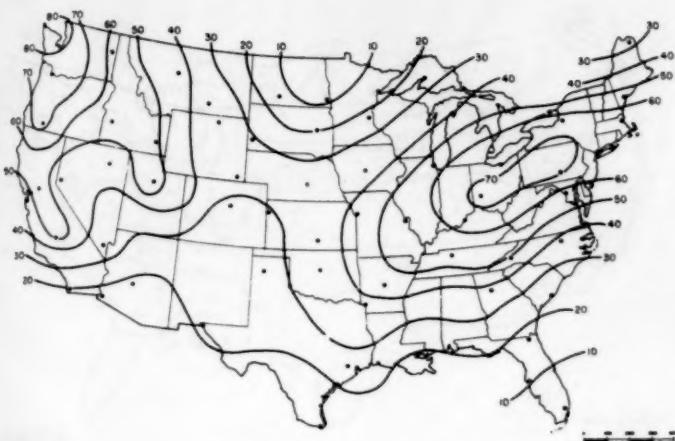
FIGURE 6.—Frequency (percent) of cold-wet conditions during January.

FIGURE 7.—Frequency (percent) of cold-wet conditions during February.

FIGURE 8.—Frequency (percent) of cold-wet conditions during March.
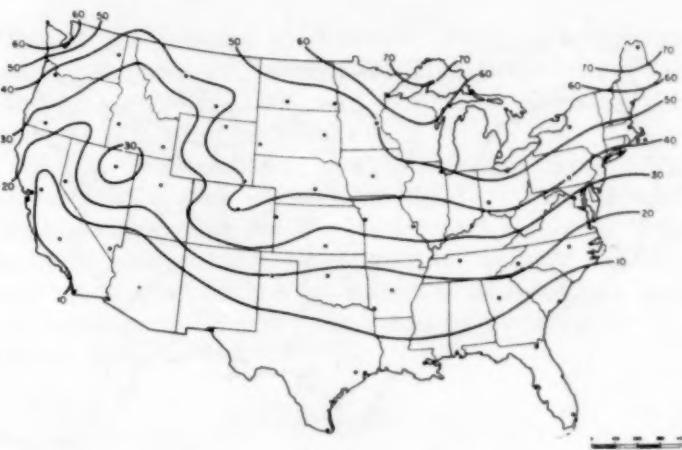
FIGURE 9.—Frequency (percent) of cold-wet conditions during April.

tinues to show the lowest frequency of cold-wet conditions.

In January (fig. 6) the decrease in frequency of cold-wet conditions in North and South Dakota continues with the frequency decreasing to between 10 and 30 percent. A decrease of 5 to 10 percent occurs in California, Oregon, and Maine, and an increase of about 10 percent is evidenced in Ohio and Pennsylvania, but with these exceptions conditions remain much the same as in December.

February (fig. 7) shows an increase in frequency in the North Central States, with slight decrease south of the Great Lakes, in Oregon, and in California. The increase noted in North and South Dakota is due to the rise in temperature following the coldest month of the year, January. In this month Miami has its greatest frequency, approximately 3 percent.

During March (fig. 8) the only significant changes in the frequency of cold-wet conditions are 10 to 20 percent increases in Minnesota, North Dakota, and South Dakota, and 15 to 30 percent increase in Maine. The extreme Pacific Northwest (Olympic Peninsula) continues to have the greatest frequency, 80 percent.

In April (fig. 9), with the retreat of the polar front and cold airmasses, an increase of 15 to 25 percent is seen in the northern Great Lakes, North Central States, and northern Maine. Decreases of 20 to 30 percent are apparent in the southern part of the country, northern California, and the Pacific Northwest. During this month northwestern Washington relinquishes its lead (for the only time) to the northern Great Lakes and Maine which have 70 to 75 percent occurence.

MAY THROUGH AUGUST

During this period cold-wet conditions occur less than 20 to 30 percent of the time throughout the country, with the following exceptions: (1) the Olympic Peninsula of Washington which has over 30 percent frequency all summer, and (2) all the northern States in May (fig. 10), with 25 to 40 percent occurrence. During June, July, and August (figs. 11 to 13), cold-wet conditions occur 10 percent of the time or more only in the far northern fringe of the country.

5. COLD-WET REGIONS

From the preceding discussion and from examination

FIGURE 10.—Frequency (percent) of cold-wet conditions during May.

FIGURE 12.—Frequency (percent) of cold-wet conditions during July.

FIGURE 11.—Frequency (percent) of cold-wet conditions during June.

FIGURE 13.—Frequency (percent) of cold-wet conditions during August.

of the monthly maps, it is apparent that the greatest frequency of occurrence of cold-wet conditions is concentrated in two parts of the country: (1) the Pacific Northwest, and (2) the States bordering the Great Lakes, especially those east and south of the Lakes. These regions may be designated as the "cores" of cold-wet conditions; that is, they are the places where the greatest frequency exists, in terms of the defined criteria. Away from these two regions there is a gradual decrease in the frequency of cold-wet conditions.

The data for the year and for the cold season, presented in the last two columns of table 1 and plotted in figures 14 and 15, show the two major cold-wet cores on a generalized basis.

The average annual frequency of cold-wet conditions (fig. 14) shows that the northern two-thirds of the country has these conditions about 20 percent of the time or more. The Pacific Northwest shows a frequency of 40 to 50 percent, and the States bordering the Great Lakes, particularly Michigan, northern Ohio, northwestern Pennsylvania, and northern New York, have 35 to 40 percent.

A slight extension into extreme northern Vermont, New Hampshire, and Maine may also be observed.

6. COMPARISONS OF FREQUENCY OF OCCURRENCE OF EACH OF THE CRITERIA

Table 2 presents the frequency of occurrence of each of the four cold-wet climatic criteria at four selected stations during January, April, July, and October. Two of the stations, Duluth, Minn., and Tatoosh Island, Wash., are in the core regions previously discussed. Nashville, Tenn., and Boston, Mass., are representative of the transition to the areas of less frequent cold-wet conditions of eastern and southern United States.

Table 2 shows that with few exceptions Criteria A (cold and precipitation) and D (cold and cloudy) occur most frequently at each station, and Criterion B (mild, wet, and windy) is least frequent.

In January at Tatoosh Island, Boston, and Nashville, Criteria A and D occur more than 50 percent of the time (67.6 percent at Tatoosh), and Criterion C (cold with snow on ground) appears as a secondary maximum at Tatoosh (14.2 percent) and Boston (13.7 percent). The

FIGURE 14.—Annual frequency (average percent per month) of cold-wet conditions. (Period of record, 1948–1953).

FIGURE 15.—Frequency (average percent per month) of cold-wet conditions during the period October through April. (Period of record, 1948–1953).

extensive occurrence of cold-wet climatic conditions during January is due to the low temperatures which occur throughout the country. The complete absence of Criterion B, (except at Nashville which shows 1.9 percent) is attributed to temperatures being at or below 60° F. at most places.

In April, the most noticeable changes are the increased occurrence of Criterion D at Tatoosh Island, the significant increase of cold-wet at Duluth (especially of Criterion C), and the decrease in all types of cold-wet conditions at Nashville. The large increase in Criterion D at Tatoosh Island indicates the continuation of winter cloudiness (18 days are cloudy) accompanied by a sharp decrease in frequency of precipitation from January to April. The increase at Duluth is due to warmer spring weather, with temperatures rising into the cold-wet range, and also to the persistence of a snow cover. At Nashville, temperatures are above the limit of the cold-wet range (67° F.) a greater proportion of the time, thereby reducing the frequency of occurrence.

In July, only Tatoosh Island and Duluth (32.2 and 15.9 percent, respectively) have significant percentage values of cold-wet conditions. The relatively low temperatures (mean daily minimum temperature during July is 51.5° F. at Tatoosh Island and 54.5° F. at Duluth) are accompanied by a summer maximum of precipitation frequency at Duluth, and by prevailing cloudiness (16

days of the month) at Tatoosh Island. Throughout most of the country, however, summer temperatures are too high, or precipitation and cloudiness too small, for cold-wet conditions to occur.

During October there is a considerable increase in cold-wet conditions at each of the four stations. Of greatest significance for this increase are the lower temperatures occurring throughout the country. Colder weather is accompanied by increases in cloudiness and precipitation at Tatoosh Island, and by increased cloudiness at Duluth.

7. CONCLUSIONS

The following generalizations are based upon data from a network of 61 representative lowland and plateau stations, and are not applicable to mountains:

a. The Pacific Northwest, especially the western part of the Olympic Peninsula in the State of Washington, has the greatest annual frequency of cold-wet conditions in the United States. In this region, such conditions occur 20 to 30 percent of the time in summer, and may be expected nearly 80 percent of the time from December through March.

b. There is a secondary center of cold-wet conditions in the northeastern part of the country, from the Great Lakes to New England. In this area, cold-wet conditions

TABLE 2.—*Frequency (percent) of separate cold-wet criteria* (for four sample stations)*

Station	Criteria				Criteria				Criteria				Criteria			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
	January				April				July				October			
Tatoosh Island, Wash.	38.6	0.0	14.2	29.0	22.8	0.0	0.0	43.2	32.1	0.1	0.0	0.0	28.5	0.0	0.0	11.3
Duluth, Minn.	7.4	.0	9.7	.1	21.9	.0	34.4	10.9	10.2	5.2	.0	.5	18.3	.1	1.2	28.6
Boston, Mass.	24.8	.0	13.7	25.6	21.5	.6	.6	23.2	.3	4.5	.0	.0	10.8	4.7	.0	5.8
Nashville, Tenn.	27.3	1.9	1.0	23.4	10.4	1.8	.0	11.2	.0	0.1	.0	.0	10.7	2.3	.0	2.4

*Criterion A—Observations with falling precipitation or fog at time of observation with temperatures from 23° F. through 59° F.
  Criterion B—Observations with falling precipitation or fog at time of observation with temperatures from 60° F. through 67° F. and wind of 5 m. p. h. or more.
  Criterion C—Observations with no falling precipitation or fog at time of observation with snow on ground and temperatures from 23° F. through 49° F.
  Criterion D—Observations with no falling precipitation or fog at time of observation with no snow on ground, with 6–10 tenths clouds, and temperatures from 23° through 49° F.

persist from 40 to 70 percent of the time from October through April.

c. The period of greatest frequency of cold-wet conditions throughout the country is October through April, although in the northern tier of States from Montana to Michigan during winter, frequency drops because of prevalence of cold-dry conditions associated with temperatures below 23° F.

d. In winter (December through February) climatic conditions in North and South Dakota are similar to those usually found in the Arctic and Subarctic during early spring and late fall, with cold-wet conditions alternating with cold-dry.

e. Of the four criteria used, Criteria A and D occur most frequently, and Criterion B least frequently.

ACKNOWLEDGMENTS

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WEATHER AND CIRCULATION OF FEBRUARY 1957 [1]

ANOTHER FEBRUARY WITH A PRONOUNCED INDEX CYCLE AND TEMPERATURE REVERSAL OVER THE UNITED STATES

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1. HIGHLIGHTS

During February 1957 the principal seat of blocking

[1] See Charts I–XVII following p. 68 for analyzed climatological data for the month.

shifted from the Gulf of Alaska to the areas of Baffin Bay and Novaya Zemlya. This displacement was associated with an index cycle characteristic of February and with a distinct warming trend in the United States.
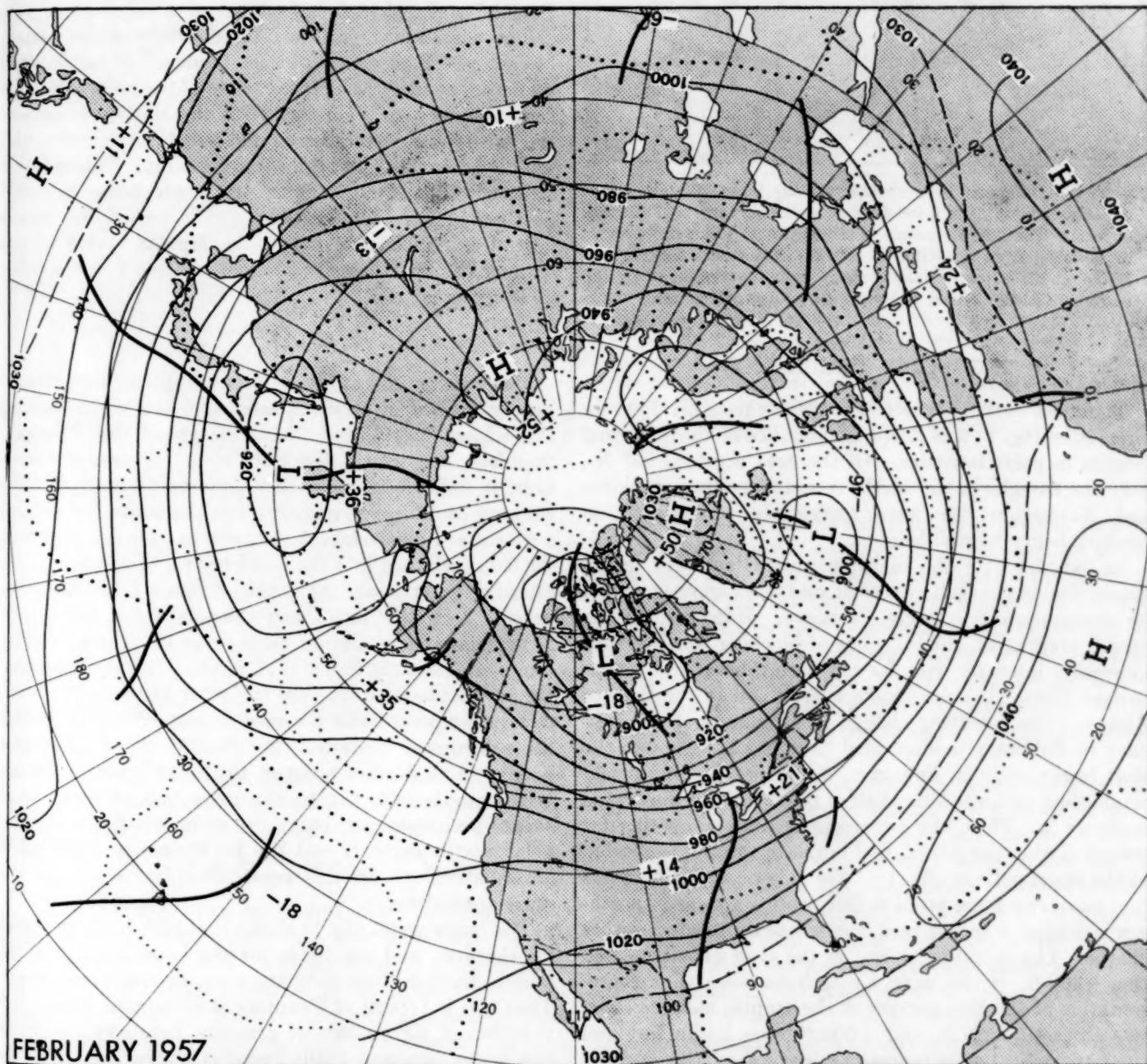
FEBRUARY 1957

FIGURE 1.—Mean 700-mb. height contours (solid) and departures from normal (dotted) (both in tens of feet) for February 1957. Extensive areas of positive anomaly at higher latitudes and negative at lower latitudes were typical low-index circulation patterns. The seat of blocking shifted during the month from its January location in the Gulf of Alaska to northern Siberia and Baffin Bay.
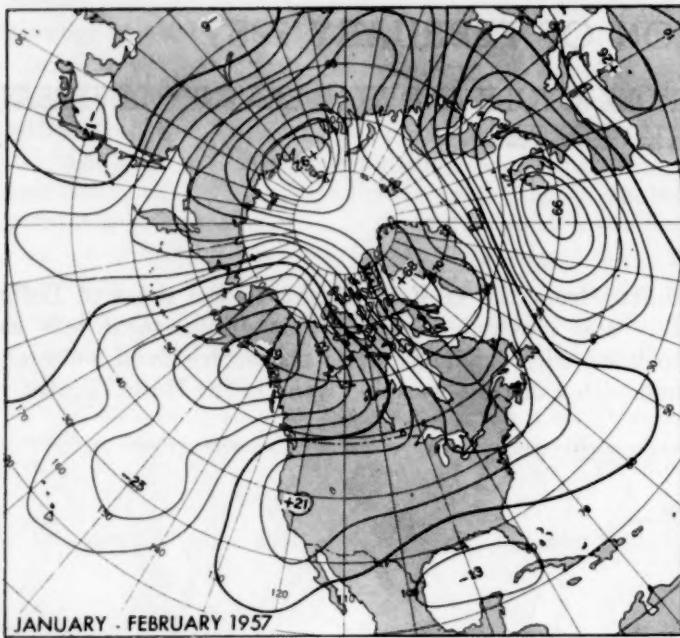
FIGURE 2.—Difference between the monthly mean 700-mb. height departures from normal for January and February 1957 (in tens of feet). The major changes were incident to the shift in locale of blocking from the Gulf of Alaska to northern Siberia and Baffin Bay. Greatly increased cyclonic development in the eastern Atlantic flooded Europe with mild maritime air.

2. GENERAL CIRCULATION

The most striking aspect of the mean monthly 700-mb. circulation (fig. 1) was the preponderance of above normal heights in polar latitudes. Of the area north of 60° N., only the troughs in the northwestern Canadian provinces and Norwegian Sea were sufficiently pronounced to produce below normal heights.

In January [10] the blocking anticyclone was firmly entrenched in the Gulf of Alaska, and this regime extended its domination into early February. However, as the month progressed, the influence of blocking was felt with increasing intensity over far northern Siberia and northeastern North America, while heights fell in the Gulf of Alaska. The resulting change in circulation from January to February is illustrated in figure 2. Though the shift began early in February, it did not become firmly established until the latter half of the month, as illustrated in figure 3. Thus, the two regimes were competing for control during the period, and both are therefore reflected in the mean pattern (fig. 1). For this reason as many as four relatively large positive DN centers appear in northern latitudes, a rather rare occurrence on mean monthly charts. The +350-ft. center in the Gulf of Alaska and the +360-ft. center near Kamchatka were thus representative of the first portion of the month, and the other two centers (+520 ft. and +500 ft. over Baffin Bay and the Laptev Sea) were representative of the latter portion. These features will be discussed further in section 4.

With above normal heights firmly entrenched at high

latitudes, cyclonic centers, with the exception of the Canadian depression, were limited mainly to southerly latitudes. Thus the Icelandic Low, though intense (−460 ft.), was depressed to the south of its normal position and produced a flow of mild maritime air into Europe (fig. 1).

In the Pacific, the very long wavelength at middle latitudes (figs. 1 and 3A) proved unstable, and a new full-latitude trough with strong negative tilt developed during the latter half-month (fig. 3B) from the Hawaiian Islands northwestward. Its southern portion was intense, with a negative anomaly of 450 feet centered just to the north of Hawaii and effected a marked change in rainfall regime in those Islands. Particularly striking in this connection is the fall center of 940 ft. (fig. 3C) in the east-central Pacific associated with this change.

The wind speed profiles further illustrate the pattern of change. Figure 4a shows the tendency of mid-latitude westerlies to increase at the expense of the polar westerlies from January to February. As the month progressed the subtropical westerlies strengthened appreciably, with middle-latitude westerly flow diminishing. This is rather strikingly illustrated in figure 4b, in which the westerlies decelerated at middle latitudes and increased only at low latitudes. Expansion of the circumpolar vortex in this manner has been described [6, 13] as often accompanying an index cycle.

3. INDEX CYCLE

Two index cycles of rather large amplitude have already been described in previous articles in this series treating this winter [3, 10], and the oscillation of this February, therefore, constitutes the third such occurrence. However, it differed in one rather important aspect from its January counterpart, namely, that the westerlies suffered a southward displacement, whereas in January they were shifted northward into the polar basin. To illustrate this interesting variation, the graph of figure 5 has been prepared. Note that in January the polar index (55° N.–70° N.) attained its maximum value (over 10 m. p. s.) and the temperate-latitude index (35° N.–55° N.) its minimum, almost simultaneously. On the other hand, in February, flow in the polar basin reversed to easterly, and this time the subtropical westerlies (20° N.–35° N.) climbed to a maximum at the low point of the index cycle. This has been described [6, 13], as the more typical sequence of events accompanying index cycles in which the circumpolar vortex expands and the jet stream is displaced to lower latitudes. In this regard the January cycle was quite anomalous.

The index graph (fig. 5) shows that high index prevailed for the first, and low index for the latter portion of the month, further illustrating the month's non-homogeneity. That this is typical of February is illustrated by the fact that five of six authors of previous February articles in this series (starting 1950) found it convenient to divide the month into two parts. This month adds a seventh instance to this list, and the circulation changes within
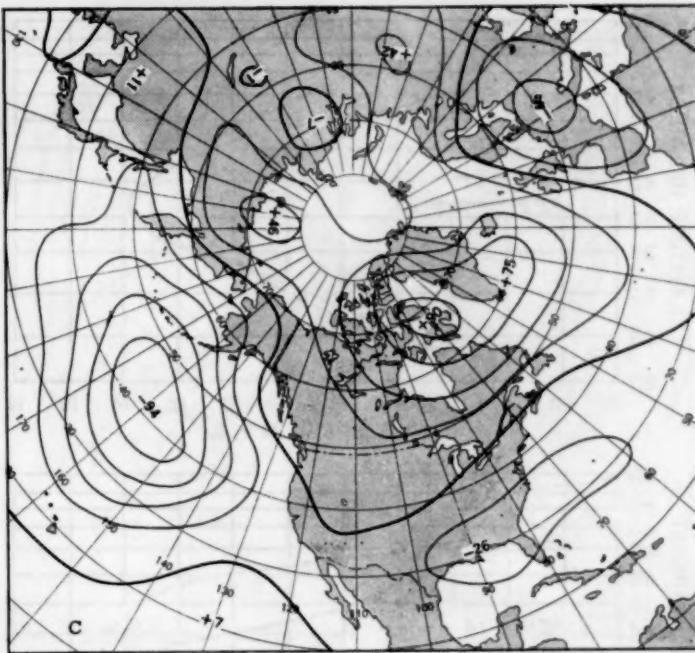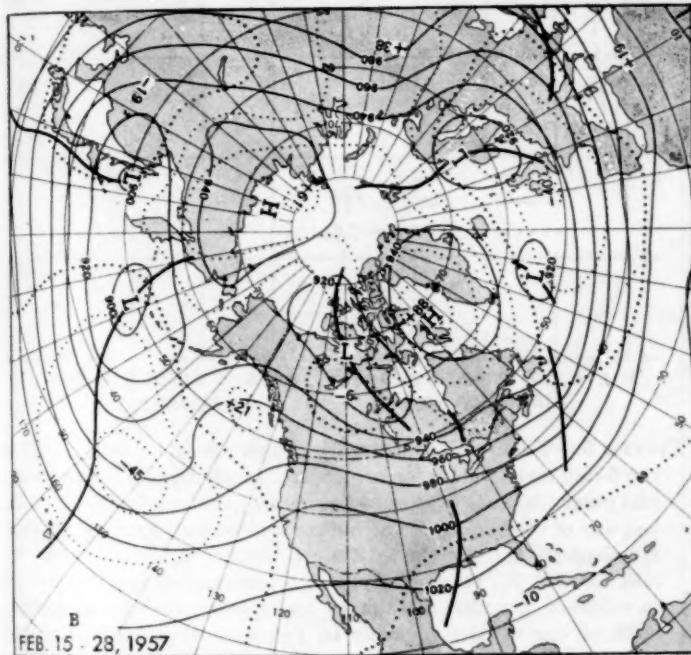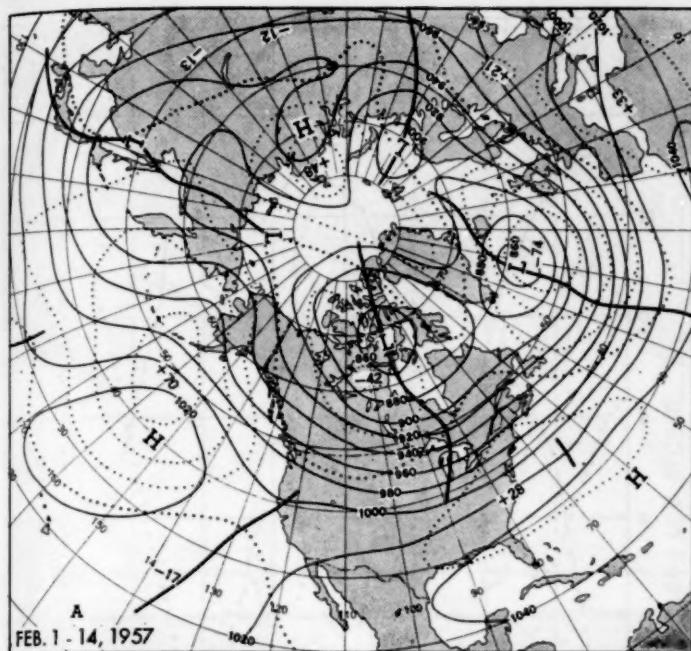
FIGURE 3.—Fifteen-day mean 700-mb. height contours (solid lines) and departures from normal (dotted lines) (both in tens of feet) for the two halves of February 1957. Part C shows the difference in height between the two periods. The January pattern, which was characterized by pronounced blocking in northern latitudes of the Pacific, carried over into February, so that most of the January-February change occurred during the second portion of the month. Note the development of the negatively tilted trough to the north of the Hawaiian Islands and the filling of the Canadian depression as blocking assumed control over northeastern Canada.

tendency to sink southward, a frequent prelude to weakening and splitting of such centers. This appears to have transpired and, at the time of the 5-day mean map centered on the 7th, one blocking surge is traceable westward to Kamchatka, while the original center weakened and continued on its southeastward course. On the mean map centered on the 14th, the original center seems to have amalgamated off the Washington-Oregon coast with a similar but retrograding center whose history is described in the next paragraph.

The second and perhaps more interesting blocking wave can be traced completely around the pole as shown in figure 6B. The following points are to be noted: 1. The block originated over Novaya Zemlya, and the first position shown is for the mean period centered January 31 with an anomaly value of +500 ft. The following week it retrograded in the well known discontinuous fashion [7], while the parent center diminished in intensity but remained in the same general locale. (Track not shown). 2. The next week it retrograded farther into the Davis Strait, where it attained maximum intensity about mid-month. Once again the blocking influence was transmitted westward, this time across Canada and

the month can best be considered by returning to a discussion of blocking, but considering its behavior this time in relation to 5-day mean periods.

4. THE BLOCKING

It has already been mentioned that blocking in the Gulf of Alaska carried over into February from the previous month. Figure 6A was prepared to study the history of this persistent feature. It traces the locus of the associated center of positive anomaly and amply illustrates its pre-eminence in the Gulf of Alaska during each week of January and into early February. The later positions however, are farther west and with a notable
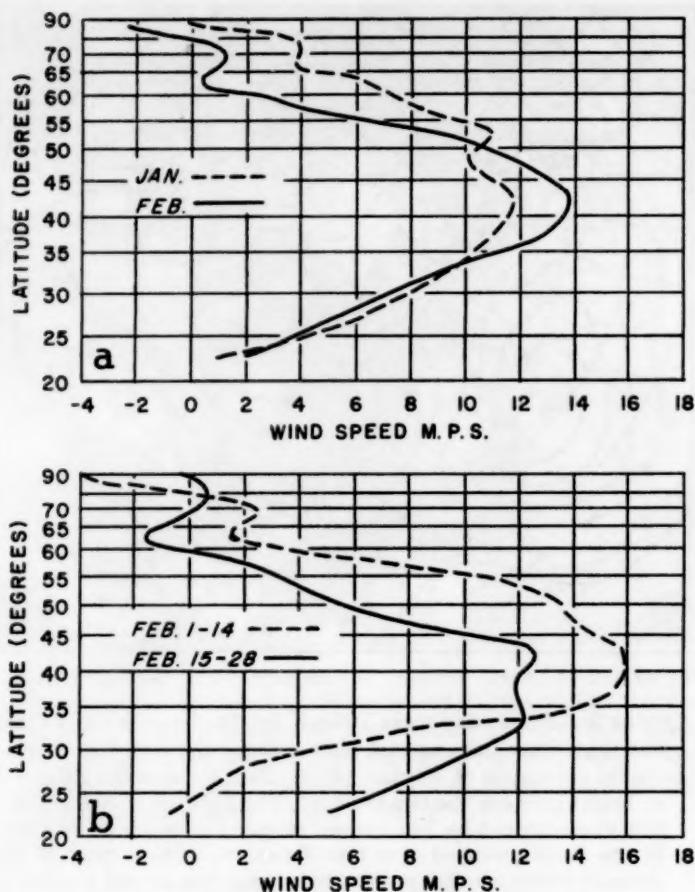
FIGURE 4.—Mean 700-mb. zonal wind speed profiles for the Western Hemisphere for (a) January and February 1957 and (b) February 1–14, and 15–28, 1957. The westerlies in the subtropics increased at the expense of first polar and then temperate westerlies.

FIGURE 5.—Time variation during January and February 1957 of the 5-day mean values for subtropical (dotted), temperate (solid), and polar (dashed) westerlies (in meters per second, plotted on the last day of the period). The indices are computed for the Western Hemisphere and for the latitude belts 20°–35° N., 35°–55° N., and 55°–70° N., respectively. Two pronounced index cycles are in evidence, but that of January was accompanied by a poleward shift of the westerlies, while in February they were displaced equatorward.

into Alaska (centered on the 21st), while the original center wandered slowly northward into Baffin Bay and weakened. 3. The whole Alaskan anomaly center then retrograded rapidly in toto across northeastern Siberia and by month's-end had returned to its point of origin. For this portion of the track it behaved as a typical "high latitude" block [2]. 4. Of additional interest with respect to the Alaskan anomaly center is the ridge retrogression which followed a course from the western Atlantic across the southern United States. It seems to have made a contribution to the +510-ft. center which appeared off the coast of Washington on the mean chart centered on the 14th and later developed into the mature Alaskan blocking center previously described. From the position off the Washington coast, the anomaly center moved northwestward at a speed of about 200 miles per day, which is unusually fast for such large positive DN centers.

The short tenure of this blocking anticyclone in the Gulf of Alaska was very important with respect to repercussions on the weather downstream over the United States. The two 5-day mean maps one week apart (figs. 7A, 7B) illustrate this. At the time of the first chart

(Feb. 14–18) the blocking High in the Davis Strait was near maximum intensity (central DN value +1,240 ft.), and the west coast ridge was rapidly developing. Note a long half wavelength between this ridge and the trough just off the United States east coast. The following week (fig. 7B), the principal blocking High proceeded rapidly westward to northeastern Siberia, heights fell rapidly in the Gulf of Alaska, and an intense depression with central value 1,050 ft. below normal appeared at middle latitudes in the eastern Pacific. The result was a complete alteration of the flow over the United States, with a rapid warming in the West. The continued stretching of the previously noted long wavelength over the United

FIGURE 6.—Trajectories of selected centers of 5-day mean positive 700-mb. height anomaly for February 1957, dated at center of 5-day period. Intermediate positions, where necessary to illustrate continuity, are shown as dots. Dashed lines are used for discontinuous, and solid lines for bodily, movement of centers. The Gulf of Alaska was the principal seat of blocking during January, and this pattern carried over into the first week of February as shown in (a). However, prior to mid-month the center of positive anomaly shifted southward, weakened, and split into two surges, one of which retrograded in discontinuous fashion toward Kamchatka and the other proceeded eastward toward the Washington coast. In (b) it is possible to trace one blocking surge completely around the pole. Note the unusually rapid retrogression of the center from the Washington coast across Alaska and into the Laptev Sea.

FIGURE 7.—Mean 700-mb. height (solid lines) and anomaly (dashed) (both in tens of feet) for the 5-day periods (A) February 14–18, and (B) February 21–25, 1957. During this time the blocking High retrograded rapidly across the Gulf of Alaska and into northeastern Siberia. An abrupt alteration of flow pattern took place over the western United States, as 700-mb. heights fell rapidly in the southern Gulf of Alaska resulting in a strong flux of warm air into the West. Note the development of a new trough along the eastern slopes of the Rockies in response to the long and expanding half wavelength between the Gulf of Alaska ridge and the trough off the east coast.

States resulted in a new trough development in the lee of the Rocky Mountains. Although this trough was weak, especially in a departure from normal sense, it was associated with the only pronounced outbreak of polar Canadian air during the month [11].
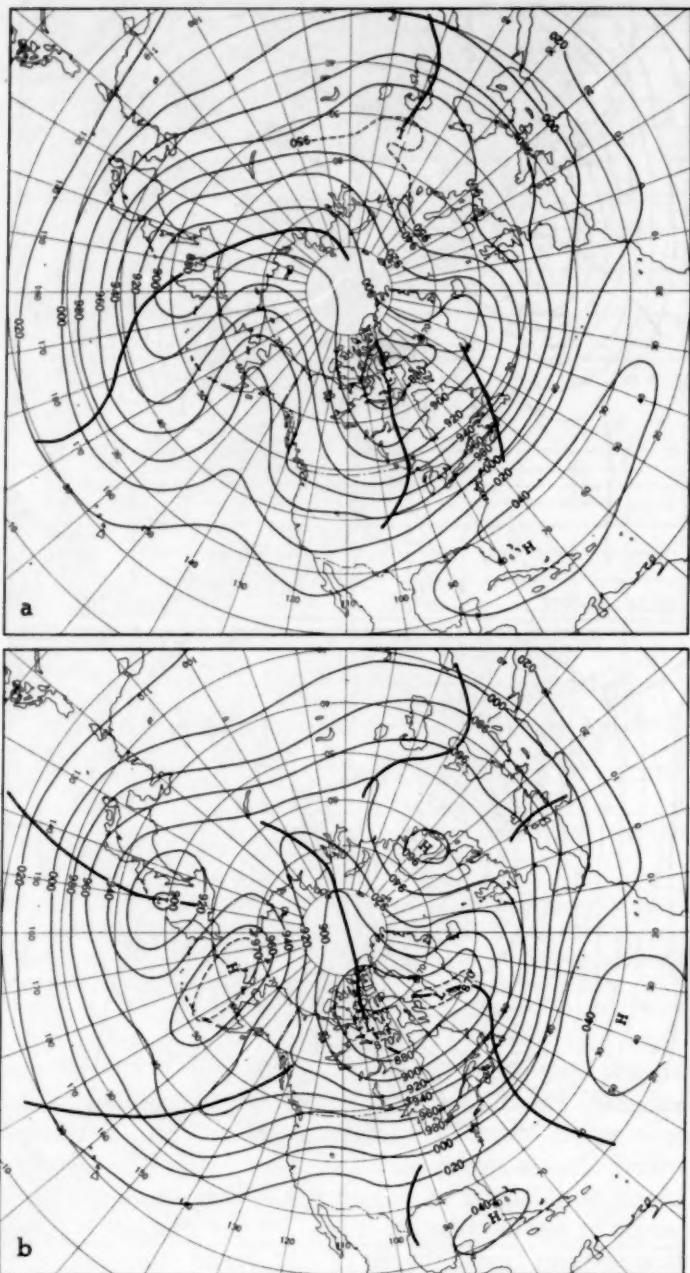
FIGURE 8.—(a) Composite chart (contours labeled in tens of feet) of five cases of 5-day mean 700-mb. maps in which a marked ridge overlay the Gulf of Alaksa just prior to retrogression. (b) Composite of the same cases after one week had elapsed. Resemblance to figure 7 is striking. The development of a new trough in the Gulf of Alaska resulted in a radical change in pattern over the United States.

This type of development, in which a Gulf of Alaska depression develops in conjunction with the retrogression of blocking Highs, has been described by Namias and Clapp [7] and Winston [15]. On a previous occasion, the author prepared a composite chart of such cases selected from the Extended Forecast Section file of 5-day mean 700-mb. charts from January 1948 through January 1957. As a criterion for figure 8a, the five largest cases of positive
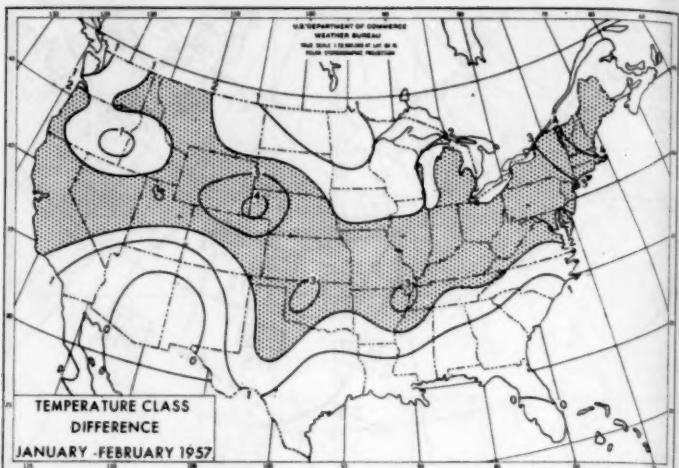
FIGURE 9.—Number of classes the anomaly of temperature changed from January to February 1957, with warming considered positive. The reversal from January is remarkable, with warming over almost all of the United States. Over a large belt through the central part of the country (stippled), a temperature increase of two classes or more occurred.

anomaly in the Gulf of Alaska just prior to retrogression northwestward were selected. Figure 8b is a composite of the 5-day mean charts for the following week.

From the close correspondence between figures 7 and 8 it is evident that a similar evoluton occurred in this instance. The result was a complete reorientation of flow pattern over the United States, in response to the new trough which developed in the eastern Pacific. Apparently this is a characteristic form of behavior of the general circulation subsequent to retrogression of strong ridges originally present in the Gulf of Alaska.

5. TEMPERATURES IN THE UNITED STATES

February 1957 was an unusually warm month in the United States. Only in the extreme northwest were monthly mean temperatures cooler than normal, and these only slightly. The change from January was very marked, and in no area did it cool even by as much as one temperature class (out of five) (fig. 9). In fact, temperatures over a broad belt extending from coast to coast across central United States warmed by two classes or more, with four-class changes observed in the vicinity of Cheyenne, Wyo., and in northeastern New England.

The corresponding change in circulation pattern is best studied from figure 2. Of importance for temperature considerations are the following:

1. The falling away of the ridge in the Gulf of Alaska as the principal seat of blocking retreated from that area. In February this ridge was much weaker and farther west than its January counterpart, so that the air flow entering western North America was mainly of maritime rather than continental origin.

2. The increase in 700-mb. height values over the whole of the United States, except for areas immediately adjacent to the Gulf of Mexico.

TABLE 1.—*New records of mean monthly temperatures (° F.) for February*

Station	February 1957		Previous maximum	
	Temperature	Departure from normal	Temperature	Date
El Paso, Tex.	57.6	+8.5	54.8	1907
Tucson, Ariz.	61.1	+7.9	60.3	1954
Corpus Christi, Tex.	66.7	+6.4	66.2	1932
Phoenix, Ariz.	61.4	+5.7	61.1	1954
Roswell, New Mex.	52.2	+7.4	50.3	1954
Las Vegas, Nev.	55.0	+4.6	54.1	1954
Macon, Ga.	58.8	+7.3	57.3	1932
Oak Ridge, Tenn.	49.1	+8.7	47.2	1949

3. The confluence which developed between the weakened (but still substantial) Alaskan ridge and the southwesterly current of tropical air from the southeast Pacific maintained a strong westerly jet across the northern tier of States. Thus cold polar Canadian air masses were largely contained.

Cold air, however, was available in quantity, judging from the thickness DN chart for the month (fig. 10). One very cold thrust did break away from the source region and enter the United States via the central Plains [11]. Several records for coldness were established at individual stations on individual days. However, considered on a monthly basis, the bulk of the cold air was contained in northwestern Canada, and a strong contrast between this air and the unusually warm conditions over the United States resulted in a very strong frontal zone along the northwestern border. This is reflected on the chart showing the frequency of occurrence of fronts over North America (fig. 11) where a maximum is indicated westward from the Great Lakes. This accounts for the near or slightly below normal temperatures observed for the month (Chart I-A) in that area. Otherwise the nation enjoyed a mild month. Along the southern border, the warm weather was unprecedented, and numerous new records were established in many areas. El Paso, Tex., for example, experienced the warmest February in 77 years' record. Other stations recording new highs for the month are listed in table 1.

It is rather unexpected that a month in which blocking played such a dominant role should be so warm over the United States. In fact, blocking is more commonly associated with cool temperature regimes to the south. However, the Baffin Bay anomaly center appears to have been too far north and the Pacific center too far west to lead to cold conditions over the United States. Of additional interest is the connection which was maintained between the former center and the mid-latitude ridge over the United States, at least in a departure from normal sense. The more usual concept associated with blocking, however, is that middle and lower latitude ridges weaken or disappear, so that no such connection maintains. This was not typical of this February nor does it typify the Februarys of the past seven years as will be discussed below.
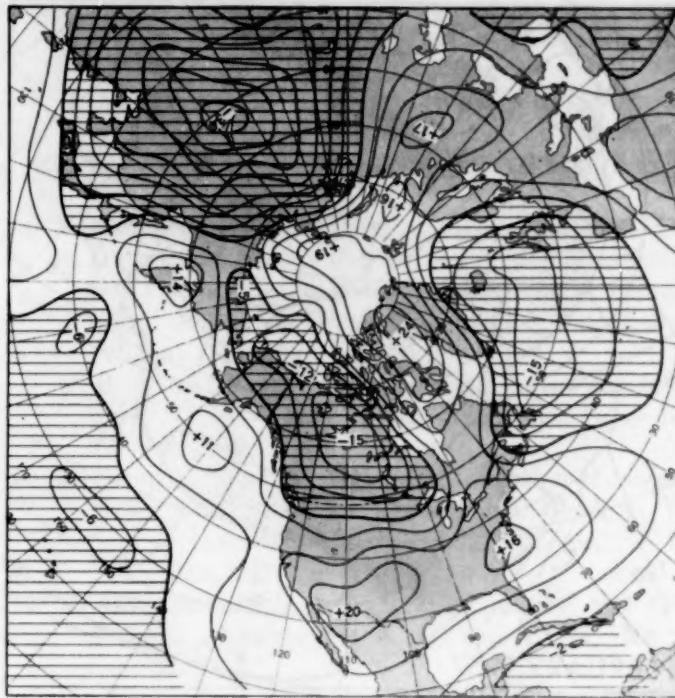
FIGURE 10.—Departure from normal of monthly mean thickness (1000–700-mb., labeled in tens of feet) for February 1957, with subnormal values hatched. The cold air in the source region of northwestern Canada was contained, and warm air predominated over the United States. Note also the extreme cold over Siberia, as contrasted to the mild regime over most of Europe.

A long-standing trend toward warm winters in the Northeast has been discussed by several authors [5, 14]. That this tendency was representative of this month is amply evident from table 2, in which mean monthly temperature departures from the new 30-year (1921–1950) normal are tabulated for the years since 1949. After 1950 not a single negative value appears and, except for that year, very warm conditions have predominated for a surprisingly long period. A composite 700-mb. chart computed for the Februarys of 1951 through 1957 (not shown) reveals that above normal heights prevailed over northeastern Canada with the maximum departure (+240 feet) centered over Greenland. Also, as mentioned in the previous paragraph, these were associated, not with negative, but with positive height anomalies over the whole of the United States. Thus, blocking in the Greenland area appears to have accompanied abnormal warmth over the United States, at least in recent Februarys.

TABLE 2.—*Mean February temperature departures from normal for selected cities in the northeastern United States (°F.)*

|	1949	1950	1951	1952	1953	1954	1955	1956	1957
New York, N. Y. (La-Guardia Field)	+6.3	−0.2	+4.0	+3.9	+6.2	+7.6	+2.6	+4.5	+5.2
Washington, D. C.	+6.7	+1.6	+1.5	+4.0	+5.5	+6.4	+0.7	+4.0	+4.3
Boston, Mass.	+5.2	−1.2	+5.5	+3.3	+5.8	+7.2	+2.8	+3.3	+5.5
Caribou, Maine	+0.9	−1.7	+5.4	+7.0	+7.6	+11.4	+5.3	+3.5	+5.7
Buffalo, N. Y.	+7.1	+0.1	+2.7	+4.4	+6.0	+5.4	+3.2	+5.5	+6.1
Elkins, W. Va.	+4.7	+1.8	+1.0	+2.8	+1.8	+3.8	+1.0	+5.3	+5.0
Lynchburg, Va.	+6.2	+0.4	+0.1	+2.2	+3.0	+4.6	+0.1	+2.5	+3.8
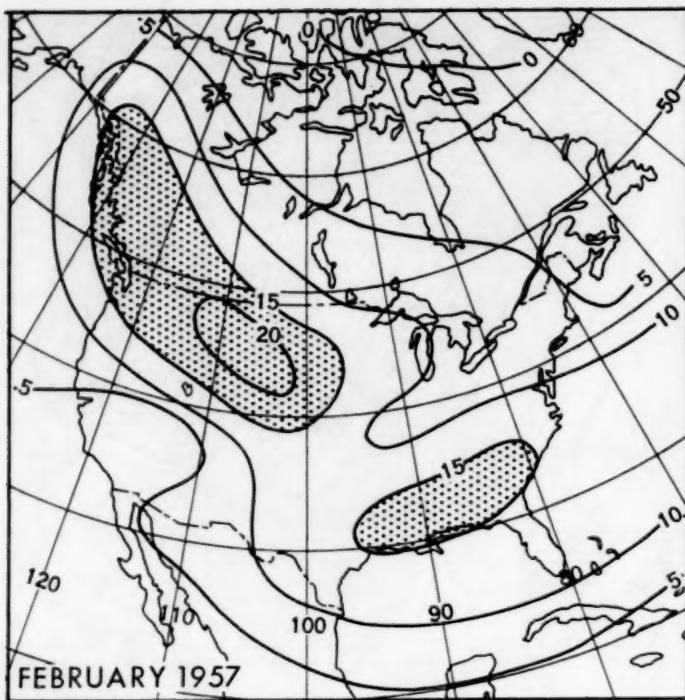
FIGURE 11.—Number of days in February 1957 with fronts of any type (within squares with sides approximately 430 nautical miles). Frontal positions taken from *Daily Weather Map*, 1:30 p. m. EST. Note high frequency of fronts in the Southeast and in the northern tier of States from the Great Lakes westward.

6. PRECIPITATION IN THE UNITED STATES

During February heaviest amounts of precipitation occurred along an axis extending from Texas east-northeastward to the Atlantic Coast. Torrential rains were recorded in the southern Appalachians, at times reaching flood proportions. This storminess began toward the end of January and resulted in severe flooding in the mountainous regions of West Virginia, Virginia, Kentucky, and Tennessee, giving rise to river crests which caused minor inundations as they moved downstream into northern Mississippi, Alabama, and Georgia. Further rains occurred in approximately the same area during the second week of February, resulting in additional flooding—this time along the Monongahela and Little Kanawha Rivers in the lowlands of southern Pennsylvania, southern Ohio, West Virginia, and Kentucky.

The precipitation pattern was associated with the confluence zone [4] apparent in the southeastern United States from the mean chart for the month (fig. 1), a feature particularly pronounced during the first portion of the month (fig. 3A). Southerly flow from the Gulf of Mexico insured an adequate supply of moist, tropical air. The region was one of frequent frontal activity (fig. 11), though it is of interest to note that there is little or no indication of a frontal temperature contrast on the mean thickness DN chart for the month (fig. 10), the principal thermal discontinuity remaining well to the north along the northern border. An interesting series of these storms is discussed by J. Badner and M. A. Johnson elsewhere in this issue.

Rainfall in Texas, Oklahoma, and in the Southwest was particularly welcome since it afforded some alleviation of the drought in those areas. Rainfall on a 6-month basis was still deficient [12] however, over much of the south-central Plains where additional rains were needed to consolidate the gains made and to bring soil moisture content up to normal levels. The central Plains States continued to be badly in need of rain, and the light precipitation of February in those areas made only a slight contribution to overcoming the long-standing moisture deficit. Copious precipitation also fell in the western United States and was fairly evenly distributed throughout the month. One particularly intense storm, which entered the west coast on the 23d, resulted in excessive rains and local flooding in northern California. These warm rains resulted from the release of moisture from warm moist air from the tropical Pacific.

7. HAWAIIAN ISLANDS RAINFALL

Cool and rainy weather in the Hawaiian Islands, a frequent concomitant of blocking in the Gulf of Alaska [9] which dominated the January pattern [10], continued into the first half of February. Two periods of kona weather occurred, though neither approximated the intensity of the January storms. However, as the pattern changed after mid-month and westerly replaced easterly flow with respect to normal (fig. 3), rainfall diminished sharply. Thus, at Lihue Airport, Kauai, the rainfall dropped from 6.99 in. to 0.10 in. from the first to the last half of the month, and at Honolulu Airport the decrease was from 2.41 in. to 0.24 in. Also of interest in this connection is the fact that the mean trough lay east of the Islands, a factor which was also unfavorable for precipitation. This is a frequent trough position in February owing to the normal speed-up of low-latitude westerlies and the fairly stationary position of the Asiatic coastal trough [8].

8. SIBERIAN WEATHER

The mild conditions which prevailed over Europe during February have already been mentioned. In contrast, Siberia was extremely cold, even for that normally frigid climate. This is confirmed by the thickness DN chart (fig. 10) which reveals values markedly lower than normal, with a central departure of −380 feet. The related circulation pattern suggests that this anomalous cold was a function of the intense blocking surge, as has already been discussed, which became firmly established in the far north over the Laptev Sea during the month. Thus, strong easterly flow with regard to normal was the rule over the whole of Siberia, both for the complete

month (fig. 1) and its individual halves (fig. 3A, B). This provided little or no opportunity for maritime air to penetrate into the area from the Atlantic, and the resultant situation permitted a deep and very cold pool of continental air to be manufactured. This pattern is in sharp contrast to February 1956 [1] in which the severe cold was confined to Europe and Eurasia, and relatively mild conditions prevailed over northeastern Siberia.

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RELATIONSHIP OF TROPOPAUSE AND JET STREAMS TO RAINFALL IN SOUTHEASTERN UNITED STATES, FEBRUARY 4-9, 1957

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1. INTRODUCTION

During the period February 4–9, 1957 persistent rains (fig. 1) occurred in the southeastern portion of the United States associated with weak wave formation on a quasi-stationary front (fig. 2) with no significant cyclone developments in the area. This paper investigates the relationship of this marked precipitation area to the tropopause break zone and jets. The investigation is made by means of a revised type of tropopause chart and a new chart, the jet level winds aloft chart, that have been routinely prepared at the National Weather Analysis Center (NAWAC) since February 1957. For convenience of study the information from the tropopause charts and jet level winds aloft charts, which give the maximum wind between 25,000 and 55,000 feet, is combined in vertical cross sections.

Although analyzed charts during February exhibited a seemingly anomalous behavior with regard to the relationship between the tropopause interruption or break-zone and the jet stream, this investigation shows that the relationship during February 4–9 was in many respects similar to the classical picture.

2. SYNOPTIC SITUATION

A cold front extending from the Middle Atlantic States through northern and western Texas at 1230 GMT, February 4, 1957 (fig. 3A) moved slowly southward thereafter, becoming nearly stationary through the South Atlantic and Gulf States by 1230 GMT, February 5. The front remained in the same general area until the morning of February 8 with numerous weak waves, only one of which developed into a deepening low center off the North Carolina coast on February 6, moving east-northeastward thereafter. A wave, gradually developing on the eastern slope of the central Rockies during February 8, moved east-northeastward, with the front in advance becoming warm and moving northward to north of the Ohio River. This wave and another wave development off the North Carolina coast on February 9 consolidated into a deepening Low in New England by 0030 GMT, February 10, with the front again moving southward as a cold front into the South Atlantic and Gulf States by 1230 GMT, February 10. Figures 3A, 4A, and 5A show the surface weather maps for 1230 GMT, February 4, 7, and 9 and figure 2 is a
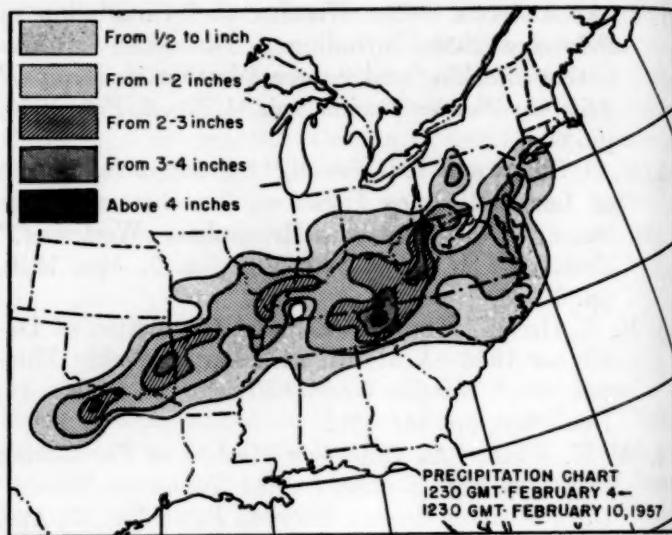
FIGURE 1.—Approximate total accumulated precipitation for the period 1230 GMT, February 4 through 1230 GMT, February 10, 1957.
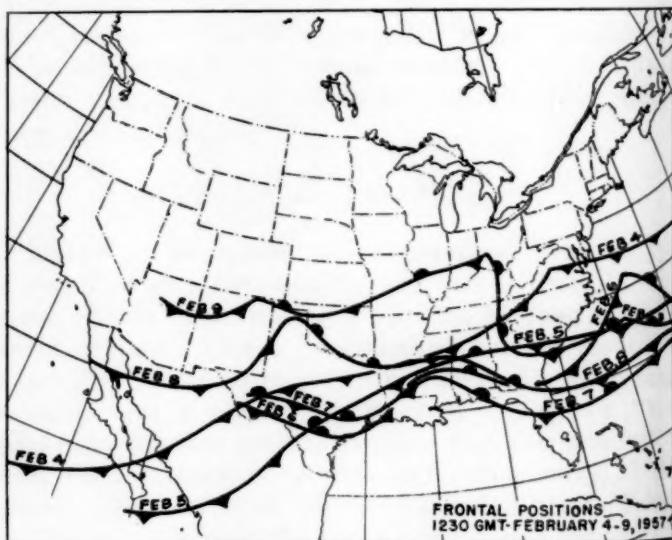
FIGURE 2.—Composite showing successive positions of fronts in southeastern United States for 1230 GMT, February 4–9, 1957.
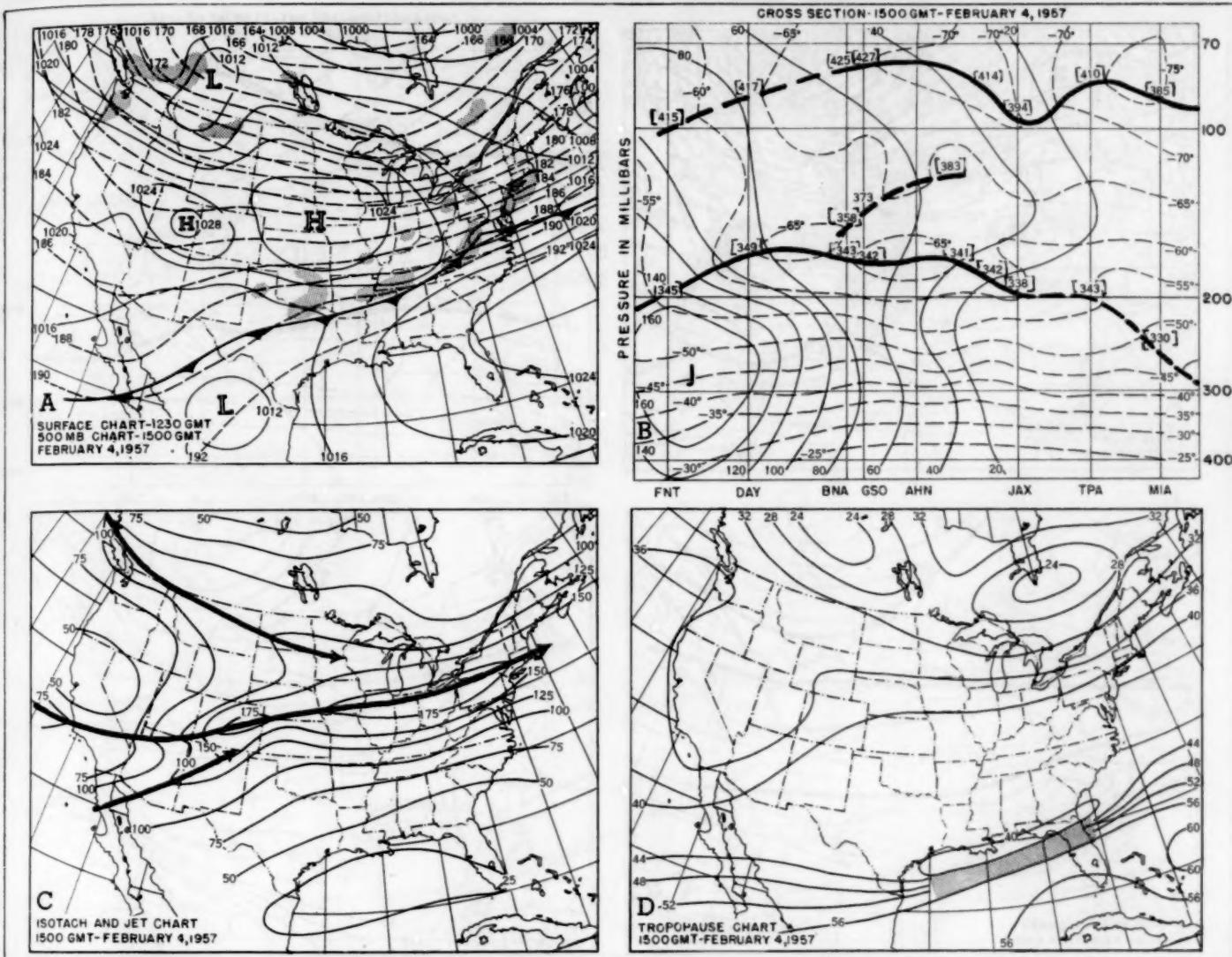
FIGURE 3.—(A) Surface map for 1230 GMT February 4, 1957, with 500-mb. contours (dashed lines) for 1500 GMT superimposed. Contours at 200-foot intervals are labeled in hundreds of feet. Stippled areas indicate current precipitation. (B) Vertical cross section above 400 mb., Flint, Mich. to Miami, Fla., for 1500 GMT February 4, 1957. Thin solid lines are isotachs at 20-knot intervals; thin dashed lines, temperature in degrees C.; heavy solid lines, tropopause; heavy dashed lines, inversions or significant stabilization levels with potential temperatures in brackets. Large "J" shows position of jet core. FNT=Flint, Mich., DAY=Dayton, Ohio, BNA=Nashville, Tenn., GSO=Greensboro, N. C., AHN=Athens, Ga., JAX=Jacksonville, Fla., TPA=Tampa, Fla., and MIA=Miami, Fla. (C) Isotach and jet stream analysis for 1500 GMT, February 4, 1957 based on jet level winds aloft chart and 300-, 200- and 150-mb. analyzed charts. Isotachs at 25-knot intervals are thin solid lines and jet streams are shown by heavy solid arrows. (D) Tropopause chart for 1500 GMT, February 4, 1957. Tropopause height contours are labeled in thousands of feet and indicated break zone is shaded.

composite giving the 1230 GMT frontal positions for February 4 through 9.

Superimposed on the surface maps in figures 3A, 4A, and 5A are the 500-mb. contours for 1500 GMT of the same days. Throughout the period February 4-9, a broad trough covered most of the United States with strong zonal flow prevailing and the winds remained predominantly from west-southwest to west in the precipitation area.

Considering the lack of wave development on the front and the zonal character of the 500-mb. flow, the precipitation (fig. 1) was quite marked in areal extent and

TABLE 1.—*Daily precipitation (inches) February 5–10, at selected stations, for 24-hour periods ending at 0730 EST. (Data provided by River Services Section.)*

| Station	February 1957						Total precipitation
	5	6	7	8	9	10	
Ft. Smith, Ark.	1.79	0.37	T	1.41			3.57
Lexington, Ky.	.10	.23	0.01	.10	0.64	0.97	2.05
Flattop, W. Va.	.08	.80	.28	.37	1.12	.47	3.21
Knoxville, Tenn.	.36	.42	.42	1.43	1.09	.28	4.00
Richmond, Va.	T	.11	.17	.27	.39	.31	1.25
Paducah, Ky.	.33	.25	.02	.29	.11	.13	1.13
Bowling Green, Ky.	.37	.25	T	.28	.41	.39	1.70
Nashville, Tenn.	.13	.06	.33	.54	.24	.37	1.67
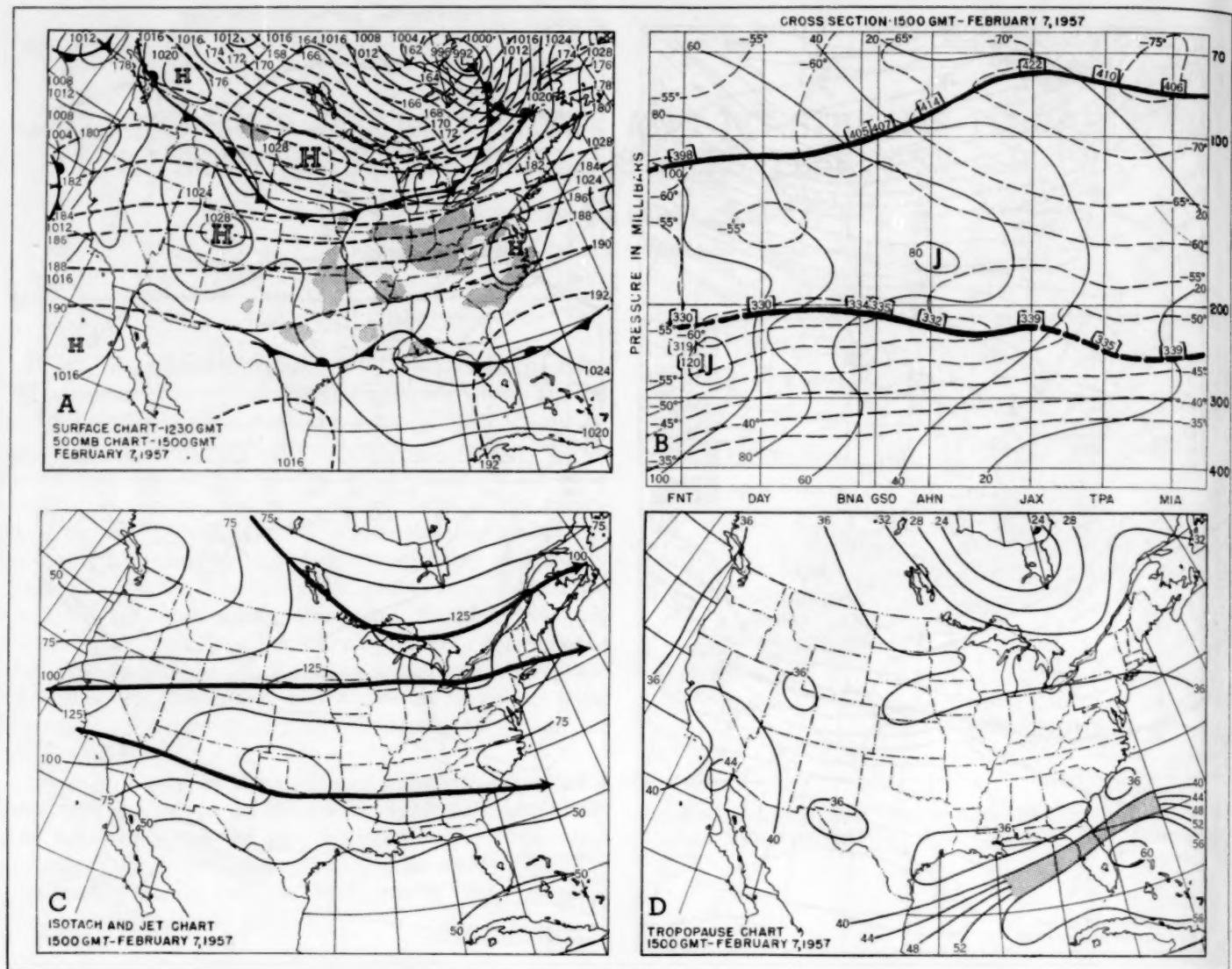
FIGURE 4.—(A) Surface map (with precipitation areas stippled) for 1230 GMT, February 7, 1957, with 500-mb. contours (dashed lines) for 1500 GMT superimposed. (B) Vertical cross section, Flint to Miami, 1500 GMT, February 7. (C) Isotach and jet stream analysis, 1500 GMT, February 7. (D) Tropopause height chart, 1500 GMT, February 7.

quantity. The area of 1.00 inch or more for the period extended quite uniformly from north-central Texas to the Middle Atlantic States, with rather erratic occurrence of heavier totals within the area. Table 1 shows the daily precipitation at selected stations throughout the area. Generally, stations in the western section of the region received most or all of their rain toward the beginning of the period, those in the eastern section toward the end of this period. Most stations in the central portion of the area had rain on each day of the period.

3. TROPOPAUSE CHARTS

Simply stated, the tropopause separates the troposphere from the stratosphere. Saucier [1] defines it as follows: "The tropopause marks a change in the vertical temperature lapse rate from rather large values in the upper troposphere to relatively small or even negative values in the lower stratosphere." Many investigators, however, have demonstrated that the tropopause is often not a single surface but exists as a multiple tropopause or layer appearing in vertical cross sections as an overlapping leaflike structure [2].

For purposes of analysis of the tropopause NAWAC has used the following definition of the "first tropopause": "The 'first tropopause' is defined as the lowest level at which the lapse-rate decreases to 2° C./km. or less, and averages 2° C./km. or less for at least 2 km. above. In addition . . . the lowest tropopause must satisfy both of the following conditions: (a) It must occur between the 600 and 30 mb. levels, and (b) its temperature must be colder than −30° C." [3]. This definition is applied ". . . so as to exclude the bases of frontal and other tropospheric stable layers." At NAWAC, methods of analysis were simplified as of February 1, 1957. Heights
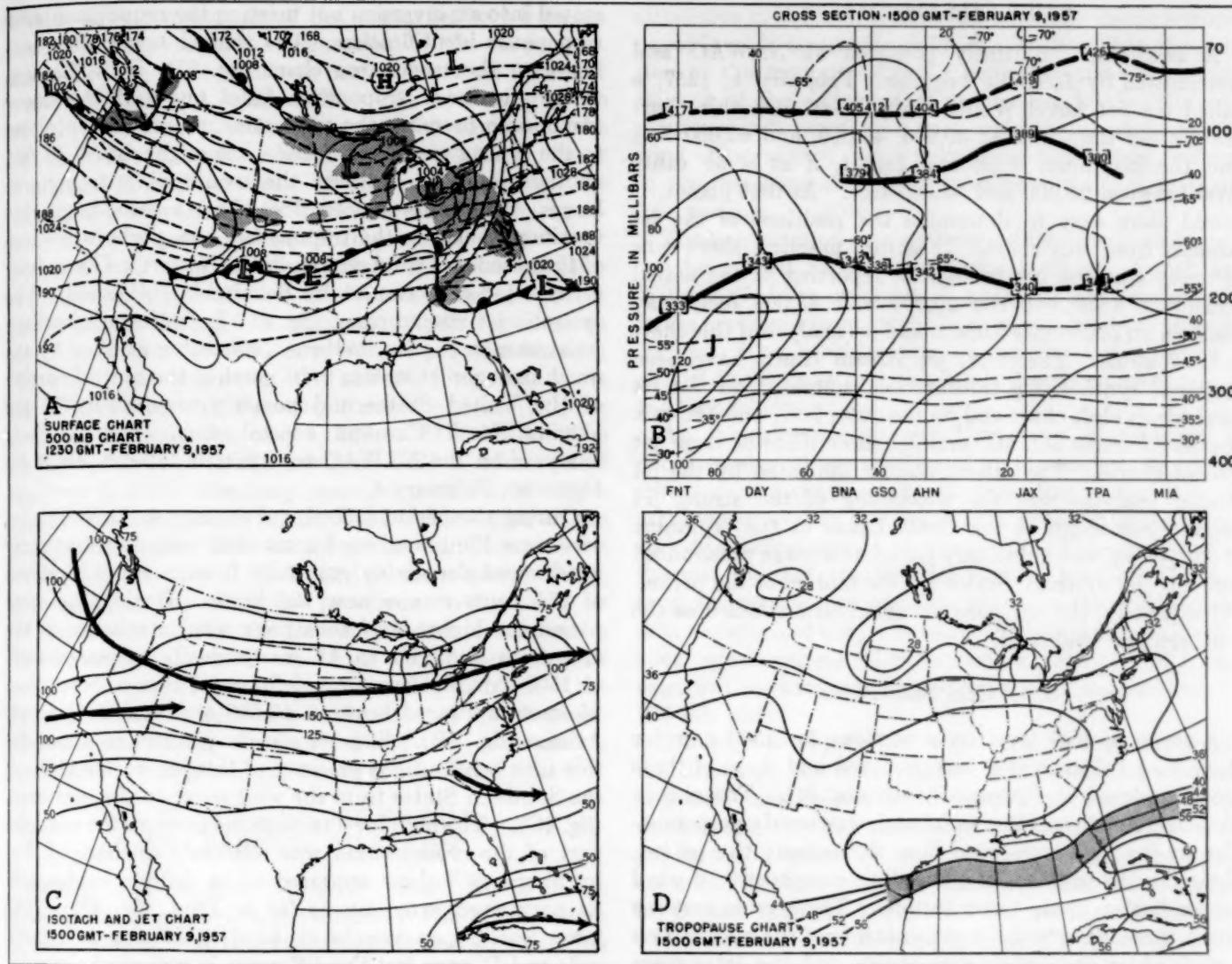
FIGURE 5.—(A) Surface map (with precipitation areas stippled) for 1230 GMT, February 9, 1957 with 500-mb. contours (dashed lines) for 1500 GMT, superimposed. (B) Vertical cross section, Flint to Miami, 1500 GMT, February 9. (C) Isotach and jet stream analysis, 1500 GMT, February 9. (D) Tropopause height chart, 1500 GMT, February 9.

of the tropopause are plotted as pressure heights in hundreds of geopotential feet and contour isopleths at 4000-foot intervals with 40,000 feet as a base are drawn. Tropopause interruptions or breaks were formerly shown as discontinuities of the height isopleths. The following convention has been substituted: When three or more contours are crowded so close that two adjacent contours are closer than ½° of latitude over a zone of 10° of longitude or more long, a shaded zone is indicated. The two bounding contours are shown continuously with intermediate contours discontinued at the inflow side and resumed at the outflow side of the zone.

Tropopause charts for 0300 and 1500 GMT, February 4–9 were examined for the purposes of this study and those for 1500 GMT of February 4, 7, and 9 are reproduced in figures 3D, 4D, and 5D. These exhibit a considerable

uniformity through the precipitation area under consideration, with a break zone present through the northern Gulf of Mexico and northern Florida and an elongated area of comparatively low tropopause heights just to the north. An area of relatively steep gradient of tropopause height oscillated from the Great Lakes region to north of the Lakes and then southward again over the Lakes during the period. However, this latter area did not meet the criteria for shading as a break zone. Of the soundings to the north of Flint, Mich., only the data at Moosonee, Ontario, suggested a slight possibility for a double tropopause or leafing structure, but the evidence was not conclusive enough definitely to establish a lower-level tropopause and, therefore, a break zone. The area between these zones maintained a relatively flat topography of tropopause heights.

4. JET STREAM CHARTS

A new chart, routinely prepared at NAWAC and transmitted by facsimile beginning February 1, 1957, is called the Jet Level Winds Aloft Chart. On this chart are plotted the winds at 30,000, 40,000, and 50,000 feet and the maximum wind and height, if at some other level between 25,000 and 55,000 feet. At first glance, it would seem easy to determine the positions of the jet streams from this chart. In actual practice, short runs at many stations, precluding the reporting of the actual maximum wind between 25,000 and 55,000 feet, may result in an inaccurate isotach and jet analysis if this chart is used alone. Therefore, jet stream charts have been prepared synthesizing information contained on the jet level winds aloft chart and on the 300-, 200-, and 150-mb. charts. Figures 3C, 4C, and 5C show three of these jet stream charts. The salient feature indicated by the jet stream analyses was the weakening of the strong jet passing just south of the Great Lakes at the beginning of the period, as a subsidiary jet became more pronounced through the southern States by the middle of the period. Subsequently, the northern jet again strengthened as the southern one weakened.

5. CROSS SECTIONS

A series of high-level cross sections for 1500 GMT for the period February 4–9 was prepared and three of these are reproduced in figures 3B, 4B, and 5B. The chosen cross section, from Flint to Miami, was nearly perpendicular to the high-level wind flow throughout the period, obviating the problem of computing components of wind perpendicular to the cross section. These cross sections give a three-dimensional representation of the information contained on the tropopause charts and the jet stream charts, and therefore furnish a convenient tool for study of these high-level features.

The most striking feature of the cross section for 1500 GMT, February 4, 1957 (fig. 3B), is the strong jet core near Flint, Mich. at 30,000–35,000 feet. The tropopause that was present above this jet core extended as far south as the Athens, Ga. area, gradually weakened southward to Jacksonville, Fla., and existed only as an inversion, not meeting the arbitrary tropopause criteria, between Jacksonville and Miami. The synoptic tropopause chart (fig. 3D), as described earlier, showed an area of comparatively lower tropopause height to the north of the Great Lakes. Although the gradient of tropopause height in this area was quite steep, the presence of a break in the tropopause could not be deduced from the evidence available. However, the lower tropopause to the north and the higher tropopause to the south of the jet core did approach the classical picture of Palmén [4]. Another distinct but higher-level tropopause extended from Miami to Jacksonville continuing northward and overlapping the first tropopause as far north as the area between Nashville, Tenn. and Greensboro, N. C., north of which it degen-

erated into an inversion not meeting the requirements for tropopause identification. The shaded break zone analyzed on the tropopause chart (fig. 3D) is in the area where the lower tropopause fades out and the upper tropopause becomes the predominant one. To conform to the typical picture of Palmén one might expect to find another jet core between the overlapping tropopause leaves. The cross section does show a secondary wind maximum between the tropopauses but, perhaps because of the absence of wind reports in the Nashville-Greensboro area, a jet core cannot be definitely established. The synoptic jet stream chart (fig. 3C) indicates a subsidiary jet stream in the far southwest, becoming masked by the much stronger jet stream to its north in the central portion of the United States and possibly reappearing in the Virginia-North Carolina coastal area. This jet was analyzed on the NAWAC transmitted 150-mb. chart for 1500 GMT, February 4.

During the period following February 4 the strong jet core near Flint weakened somewhat with the maximum wind speed decreasing gradually from a value in excess of 175 knots to one near 120 knots. During the same period the higher-level subsidiary wind maximum in the area from Nashville to Athens gradually increased until at 1500 GMT, February 7 a definite jet core of more than 85 knots appeared between 40,000 and 45,000 feet over Athens (fig. 4B). The composite jet stream chart for this time confirms the presence of this jet stream through the Southern States from the west coast to the east coast (fig. 4C). The high-level tropopause through the southern part of the cross section was relatively unchanged, but by February 7 there appeared to be definite evidence of its northward extension as far as Flint (fig. 4B). The lower-level tropopause also changed little between Jacksonville and Dayton but the difference in potential temperature of the tropopause levels at Dayton and Flint suggests the possibility of a minor tropopause break near the jet core between Dayton and Flint. However, the slight difference in potential temperature of the tropopause levels in this area makes this conclusion quite doubtful and this point is presented only as an analytical peculiarity of the data. With the development of the jet core near Athens the shaded tropopause break zone on the corresponding tropopause chart (fig. 4D) more nearly approximated the classical picture.

Following February 7, the trend of events changed and by 1500 GMT, February 9 (fig. 5B), the situation was reverting to that presented at the beginning of the period. The jet core between Flint and Dayton increased to values greater than 130 knots and that at higher levels in the Athens area subsided into a secondary wind maximum as on February 4. However, in this case highest wind speeds in the Nashville to Athens area were associated with the higher-level secondary wind maximum near 45,000 feet. The wind maximum near the same level in the Miami-Tampa area appears to be a reflection of another jet stream over Cuba.

With the strengthening of the strong jet core between Flint and Dayton the configuration of the tropopause changed to one quite similar to that observed on February 4 between Flint and Jacksonville. The weakening of the second jet core seems to be connected with changes in the high-level tropopause. A segment of relatively lower tropopause formed between Nashville and Tampa and the high-level tropopause which had conformed to the qualifications for tropopause identification on February 7 now existed as a level of significant stabilization[1] from Flint to Tampa with a southward extension as a definite tropopause through Miami. A similar situation appeared on the cross section for 1500 GMT, February 5 (not shown). The tropopause chart (fig. 5D) and the jet stream chart (fig. 5C) for 1500 GMT, February 9 exhibited features quite similar to those for February 4 (figures 3D and 3C). The shaded break zone in the northern Gulf of Mexico still persisted and the relatively stronger gradient of tropopause height reappeared in the Great Lakes region on the tropopause chart. The strong jet stream through the north central portion of the United States reasserted itself, again masking the subsidiary jet stream to the south on the jet stream chart. On February 4 the jet maximum through the southern Great Lakes was directly to the south of the area of lowest tropopause heights north of the Great Lakes. On February 9, the area of lowest tropopause heights was in the Dakotas and the jet maximum was located correspondingly to the south of this area.

6. TROPOPAUSE, JET STREAM, AND RAINFALL RELATIONS

Palmén and Nagler [5] have constructed a mean cross section in a case of approximately westerly flow over North America, and Riehl et al. [6] have used this cross section in a description of the synoptic structure of the jet stream. The cross sections presented here are remarkably similar to Palmén's mean cross section as described by Riehl. The "tropical" and "extratropical" tropopauses southward from the main jet stream core are well delineated on our cross sections, with temperatures, potential temperatures, and areal extent of the same general character as on the mean cross section. The "polar" tropopause, however, is not clearly delineated. The steepening of the tropopause height slope through the jet core and the lower tropopause to the north does have some resemblance to Palmén's cross section. (See discussion of figs. 3B and 3D.) Riehl also described the second jet, less intense than the first, between the "tropical" and "extratropical" tropopause leaves, also found on our cross sections (figs. 3B, 4B, and 5B). It therefore seems evident that the seemingly anomalous relationship of tropopause break zone and jet stream referred to in the introduction is not necessarily an unusual one. Throughout this period, tropopause leaves, or inversions not meeting the criteria for tropopause identification, were present as overlapping

[1] Significant stabilization is defined at NAWAC as a layer where the lapse rate is 3° C. per kilometer less than the lapse rate in the layer immediately below.

structures in the area of our cross sections. Since a tropopause level is arbitrarily defined, it follows that the position of the tropopause break zone depends only on the rigidity of the definition of tropopause level. No clear relationship between a jet core, which is based on definite wind observations, and a tropopause break zone, varying in position depending on tropopause definition, is therefore possible.

The precipitation area under consideration in this study can be related to these high-level features. Smith and Wilhelm [7] have investigated a situation of precipitation to the north of a front on the basis of low-level convergence factors. The consideration of high-level divergence is also of importance and this study has been restricted to the high levels.

An investigation at the University of Chicago [8] demonstrated, theoretically and by the analysis of vertical cross sections, the necessity for ascending motion immediately below and to the north of a zonal wind maximum and descending motion to the south. This suggested to Starrett [9] that the vertical motion postulated should tend to increase precipitation to the north and decrease it to the south of the jet stream. His observations showed that concentrations of precipitation activity did indeed exist in the vicinity of the jet stream as analyzed on the 300-mb. chart.

The high-level jet which was found through the Southern States on the cross sections and jet stream charts of this study can be related to the precipitation area under consideration in the same way. The great bulk of the precipitation occurred to the north of this jet where ascending motion could be inferred. However, it might be argued that the lower-level and stronger jet stream, which continued with varying intensity to the north of the precipitation zone throughout the period, indicated descending motion and thus should have inhibited precipitation. Riehl et al. [6] have developed a model illustrating the relation of the jet stream to pressure changes using changes in vorticity aloft, and inferred that precipitation will occur where the pressure is falling. His model showed that when a traveling wind maximum is moving in a straight westerly jet stream the right rear quadrant of the jet maximum is a favored area for pressure falls indicating ascending motion aloft. In an anticyclonically curved jet stream this quadrant is also a favored area for pressure falls and may be also in a cyclonically curved stream. The jet stream charts for the period indicated that the jet stream to the north of the precipitation area varied in intensity from day to day, and jet maxima could be detected moving eastward along the stream (see figs. 3C, 4C, and 5C).

The conclusion can therefore be made that as the individual jet maxima moved along the northern jet, the ascending motion to the north of the southern jet was alternately reinforced and opposed, and that it was during the periods of reinforcement that the precipitation occurred. Examination of the precipitation patterns on

the surface maps throughout the period shows the intermittent character of the precipitation. At any given time precipitation was quite spotty and the precipitation areas could easily be tracked moving from west to east (see table 1 and figs. 3A, 4A, and 5A). The assumption that the precipitation was associated with the ascending motion which could be deduced between the two jet streams seems therefore tenable.

ACKNOWLEDGMENTS

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Mariners Weather Log

A new bi-monthly publication containing meteorological information for the maritime industry, including weather and shipping on the Great Lakes as well as oceanic areas, recently began issuance under the title *Mariners Weather Log*. The first issue was dated January 1957. Each issue usually contains two major articles and several smaller contributions of current maritime interest. Recent ocean weather is described and a table of selected ship gale observations is included. Annual subscription, $1.00; additional for foreign mailing, 25¢; 20¢ per copy. Orders should be addressed to Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

Chart I.   A. Average Temperature (°F.) at Surface, February 1957.
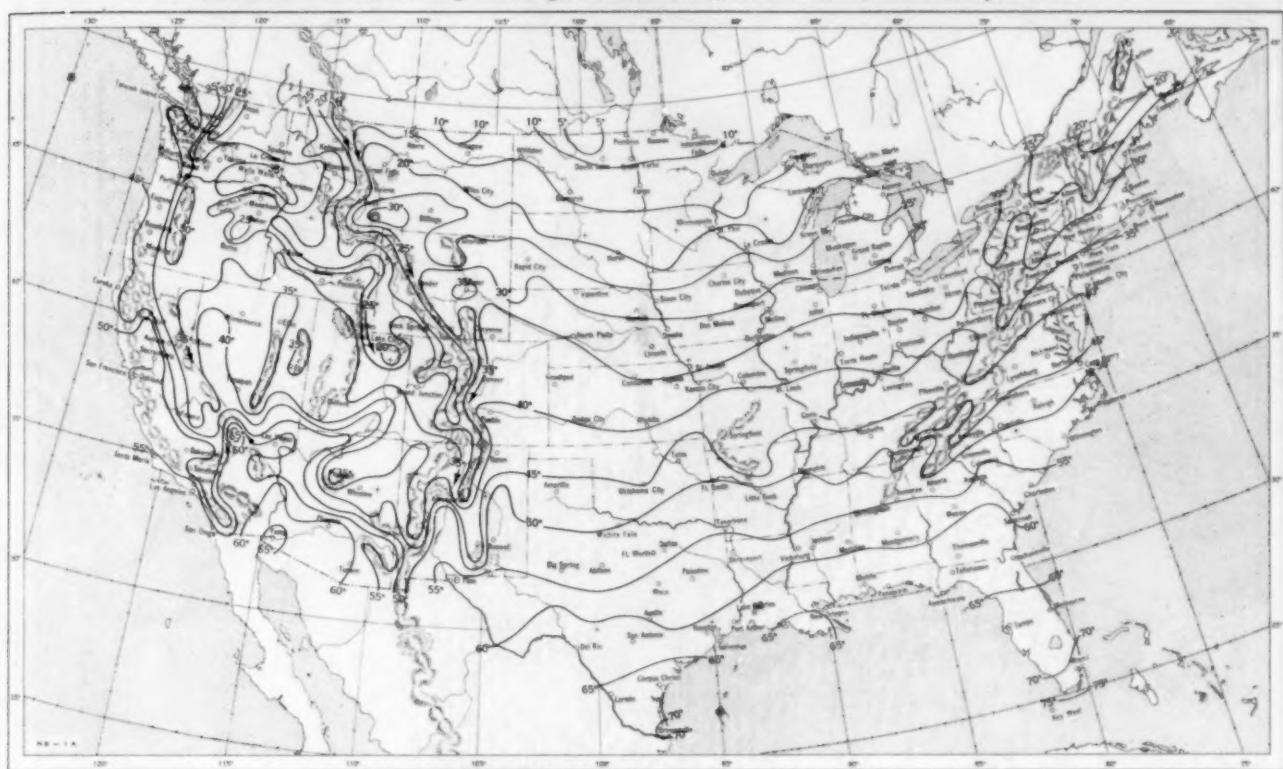
B. Departure of Average Temperature from Normal (°F.), February 1957.
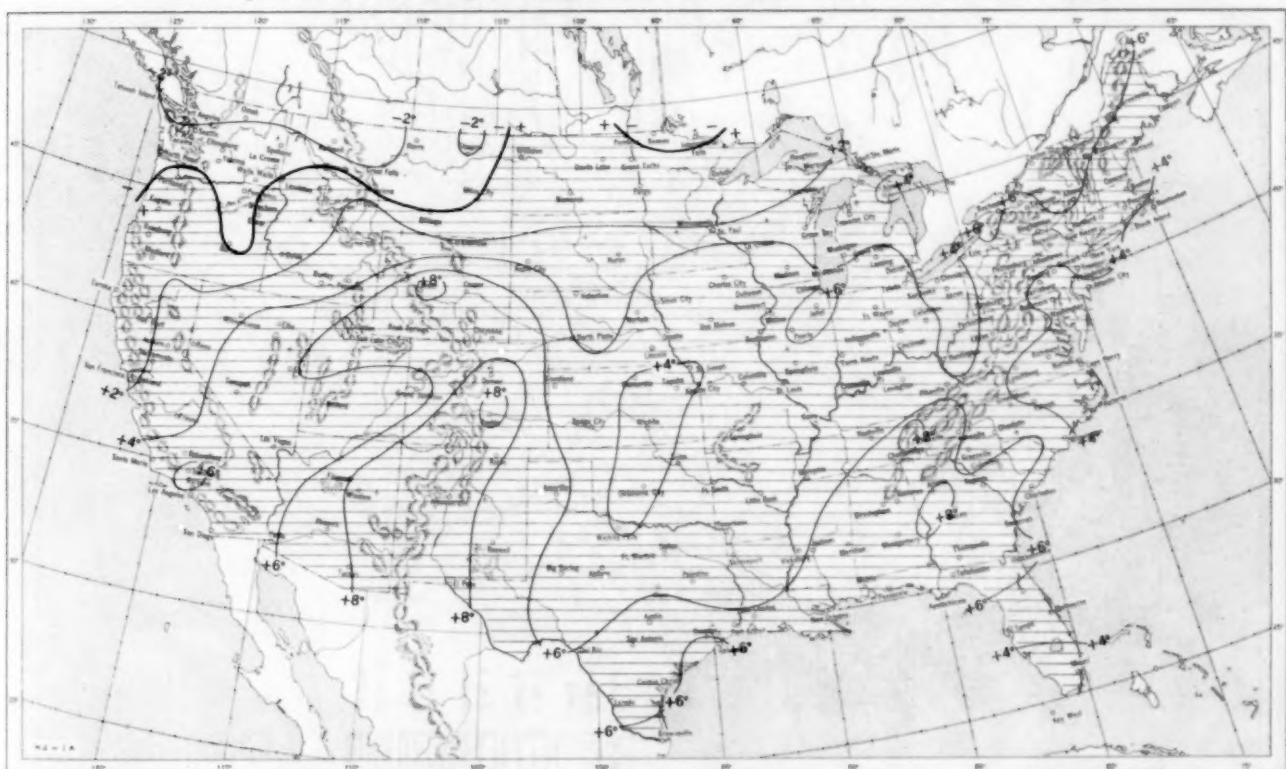
A. Based on reports from over 900 Weather Bureau and cooperative stations.   The monthly average is half the sum of the monthly
average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Departures from normal are based on the 30-yr. normals (1921-50) for Weather Bureau stations and on means of
25 years or more (mostly 1931-55) for cooperative stations.

Chart II.   Total Precipitation (Inches), February 1957.
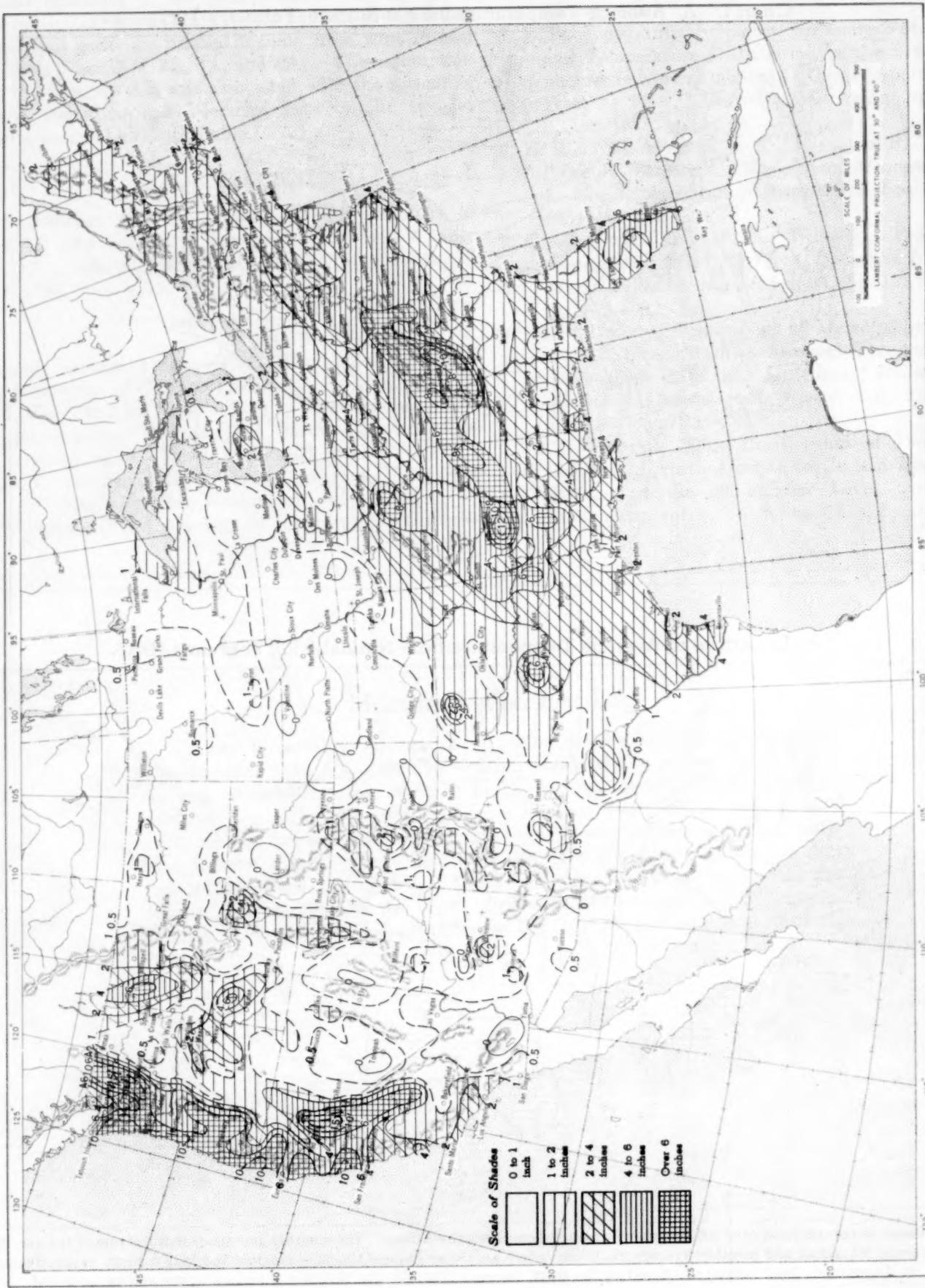
Based on daily precipitation records at about 800 Weather Bureau and cooperative stations.

Scale of Shades

0 to 1 inch

1 to 2 inches

2 to 4 inches

4 to 6 inches

Over 6 inches

Chart III.   A. Departure of Precipitation from Normal (Inches), February 1957.
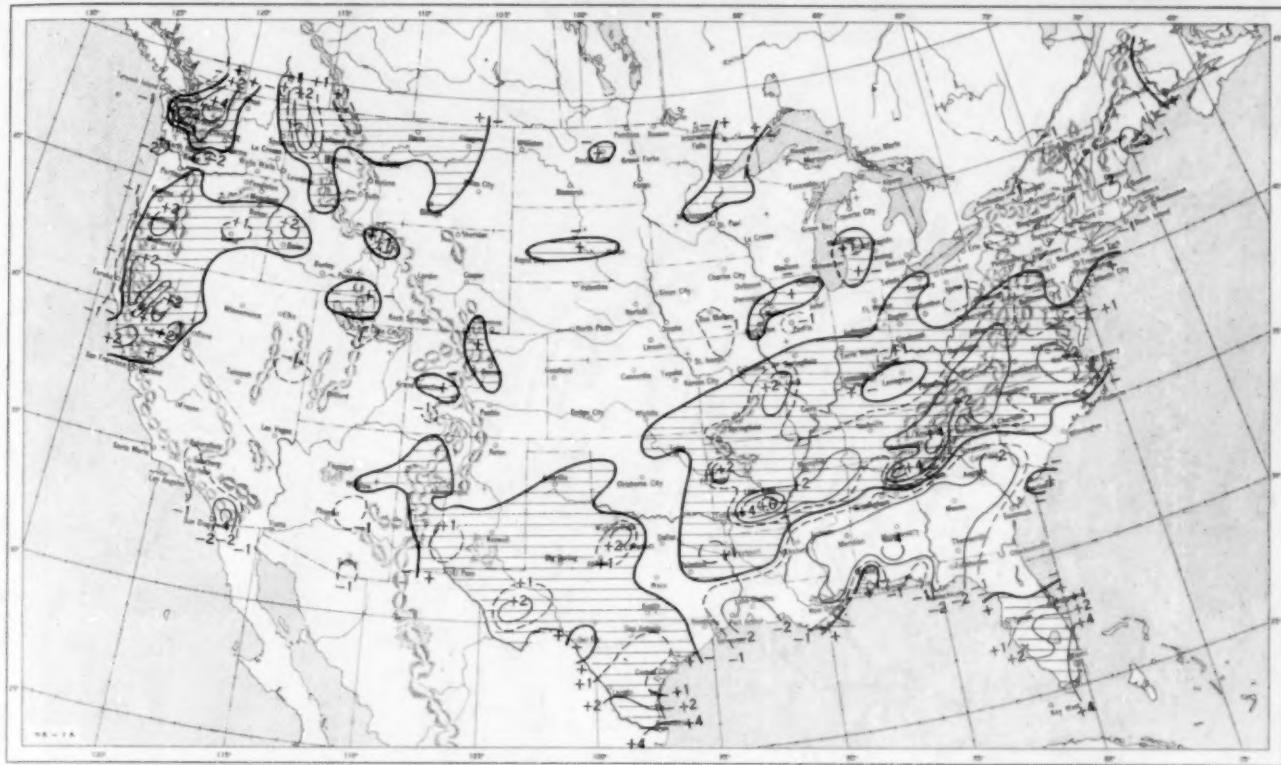
B. Percentage of Normal Precipitation, February 1957.
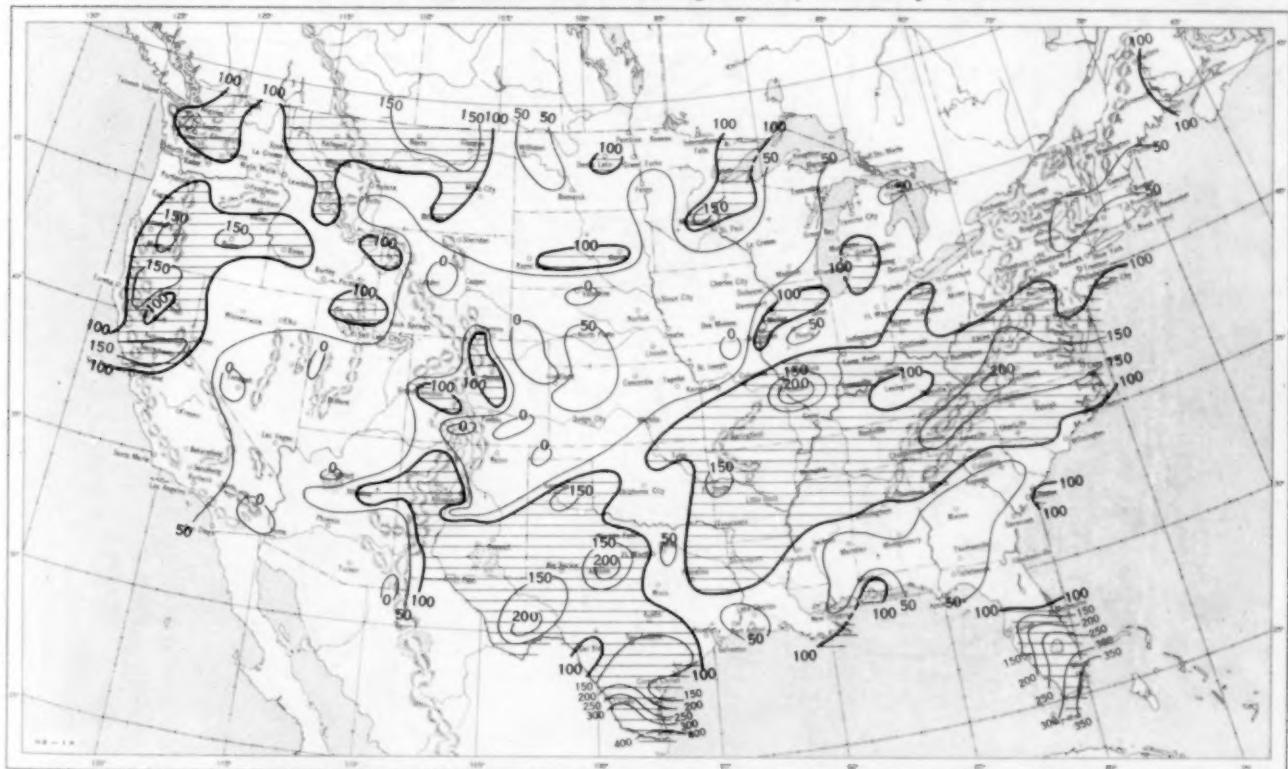
Normal monthly precipitation amounts are computed from the records for 1921-50 for Weather Bureau stations and from records of 25 years or more (mostly 1931-55) for cooperative stations.

Chart IV.   Total Snowfall (Inches), February 1957.
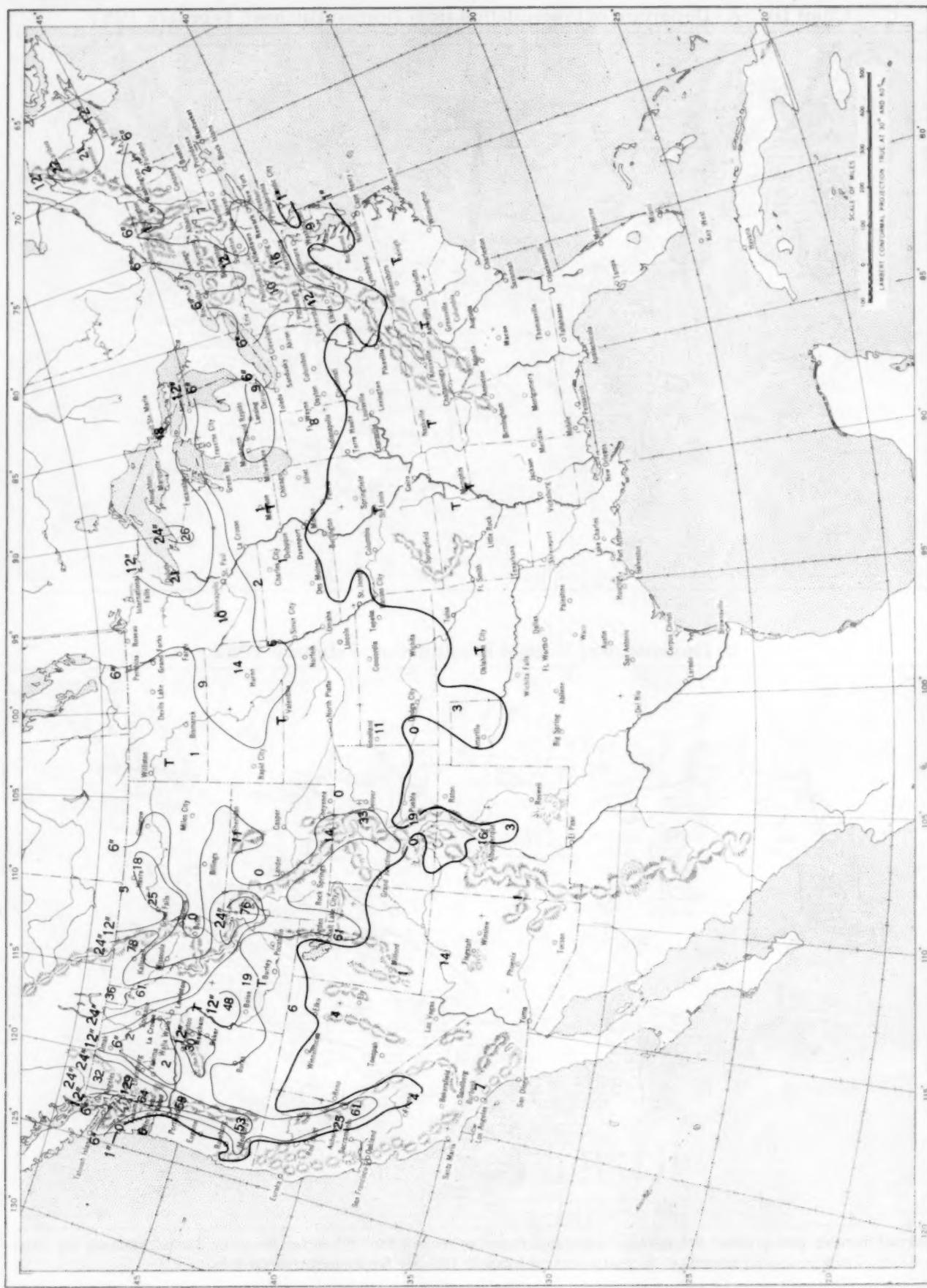
This is the total of unmelted snowfall recorded during the month at Weather Bureau and cooperative stations.   This chart and Chart V are published only for the months of November through April although of course there is some snow at higher elevations, particularly in the far West, earlier and later in the year.

Chart V.   A. Percentage of Normal Snowfall, February 1957.

B. Depth of Snow on Ground (Inches). 7:30 a. m. E. S. T., February 25, 1957.
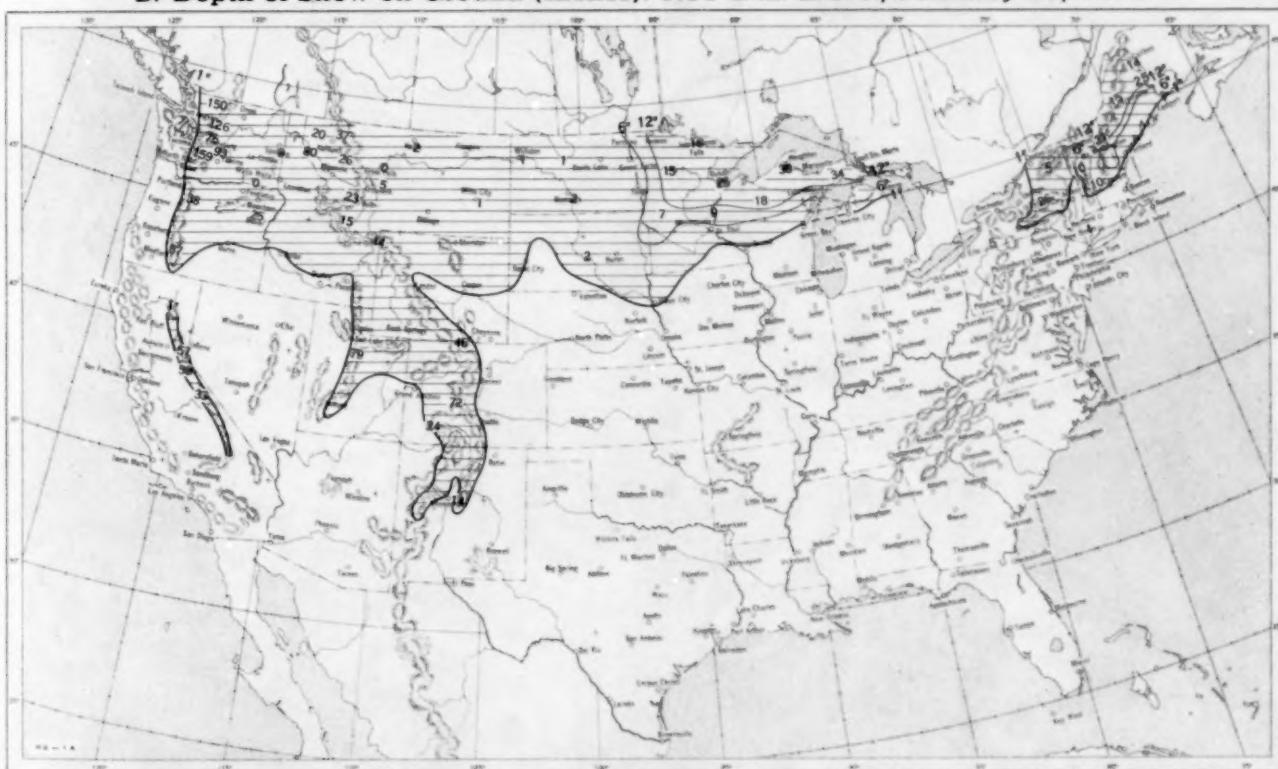
A. Amount of normal monthly snowfall is computed for Weather Bureau stations having at least 10 years of record.
B. Shows depth currently on ground at 7:30 a. m. E. S. T., of the Monday nearest the end of the month.   It is based on reports
from Weather Bureau and cooperative stations.   Dashed line shows greatest southern extent of snowcover during month.

Chart VI.   A. Percentage of Sky Cover Between Sunrise and Sunset, February 1957.
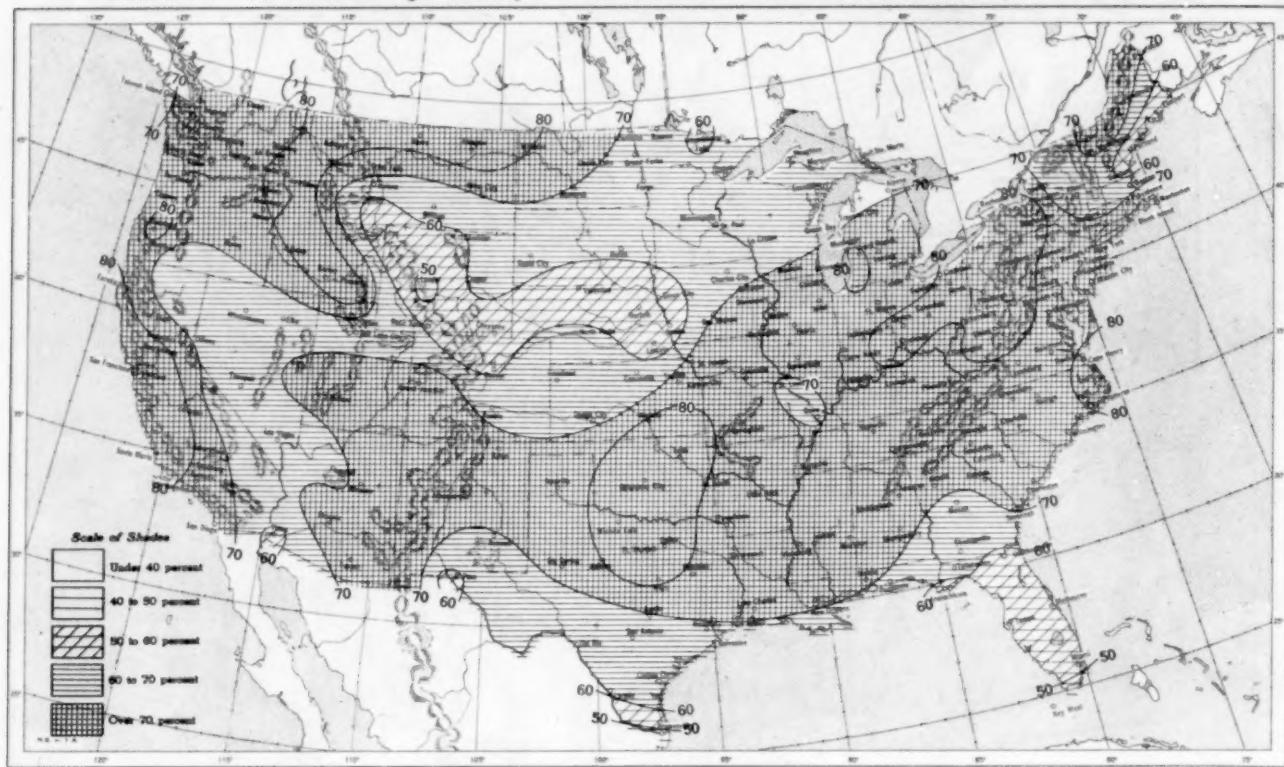

B. Percentage of Normal Sky Cover Between Sunrise and Sunset, February 1957.
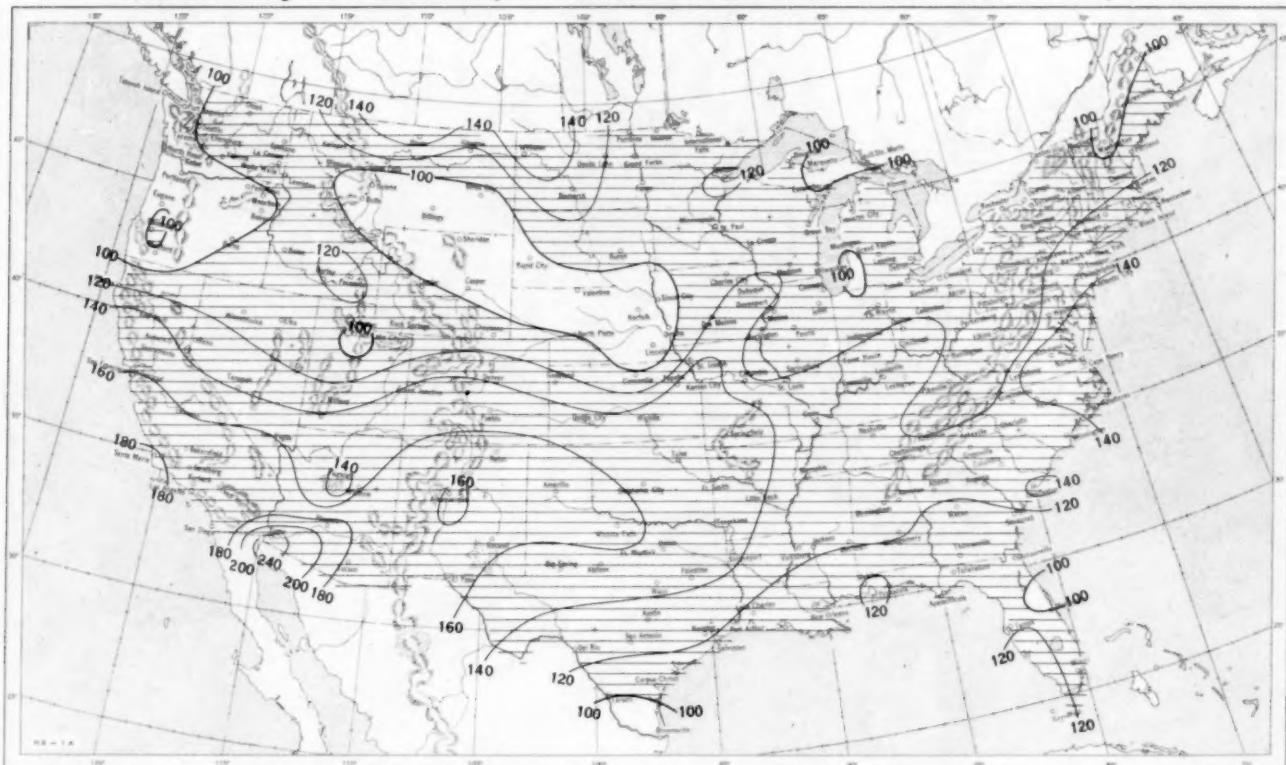
A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc.   Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month.   B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII.   A. Percentage of Possible Sunshine, February 1957.
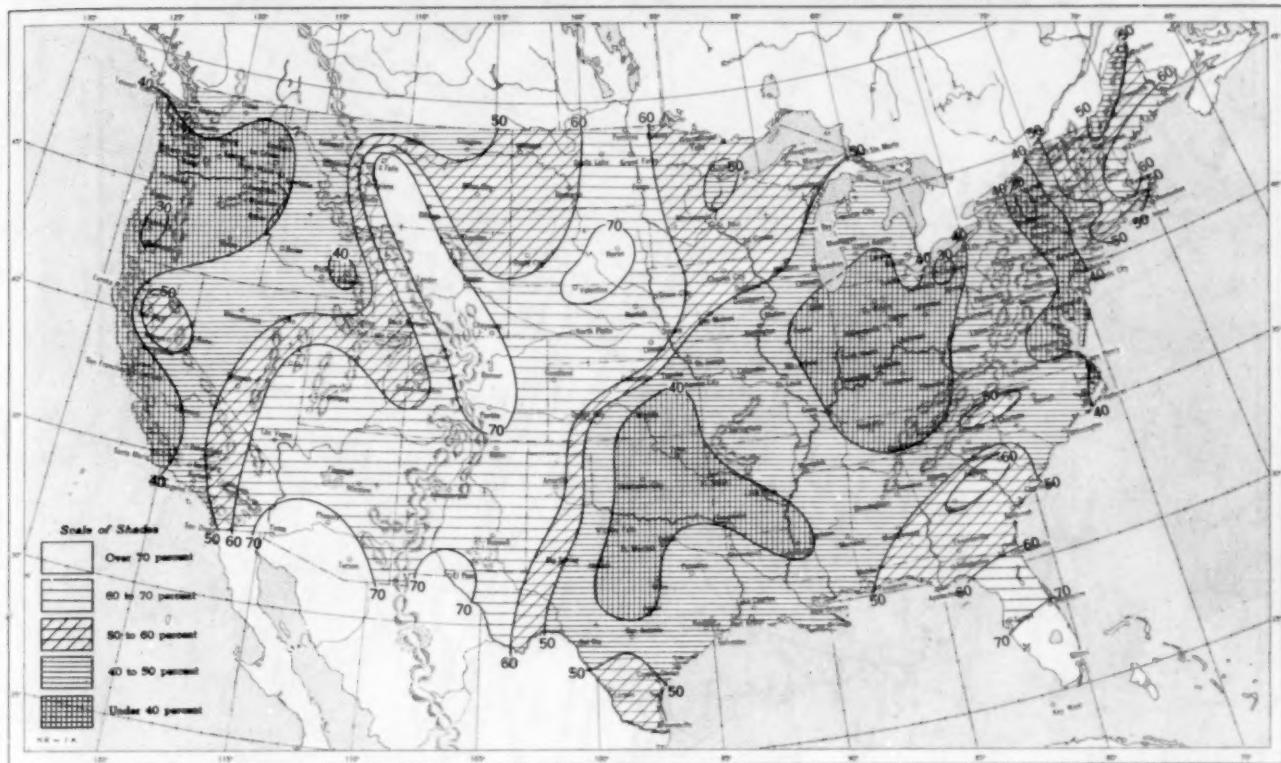
B. Percentage of Normal Sunshine, February 1957.
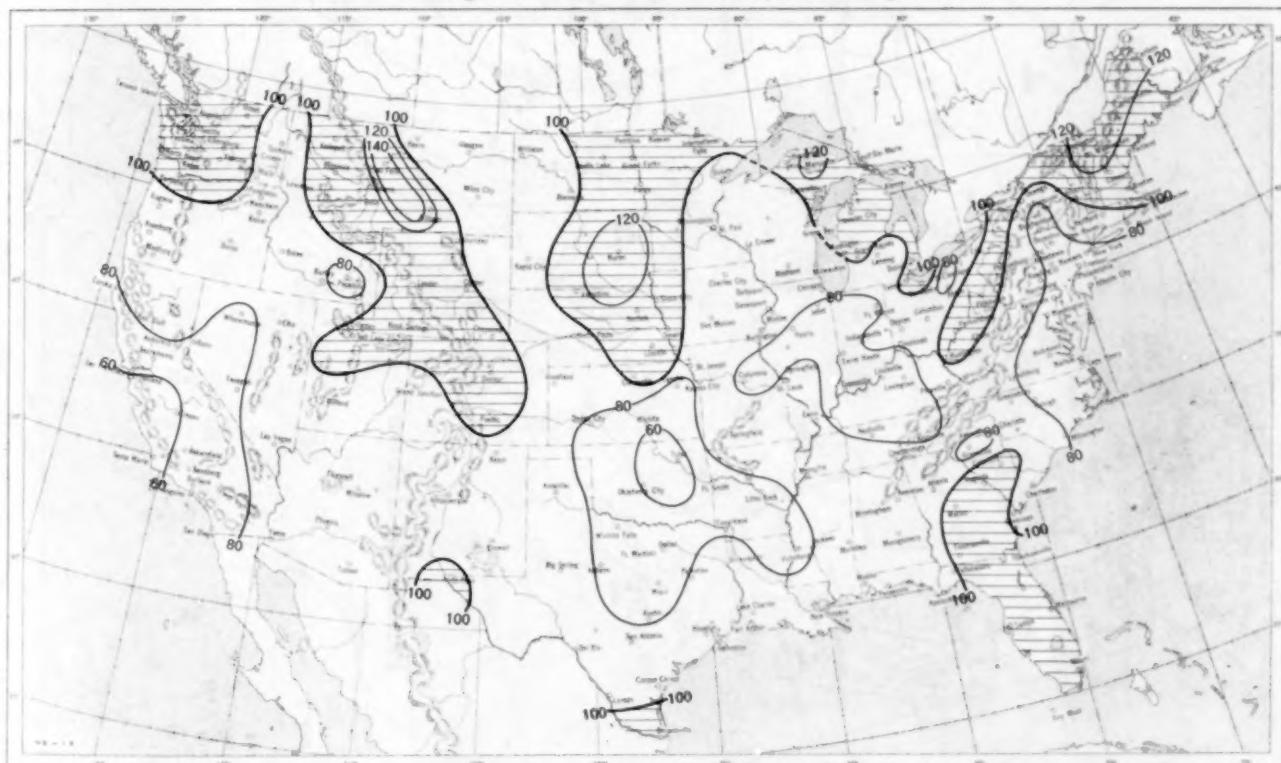
A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month.   B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, February 1957. Inset: Percentage of Mean Daily Solar Radiation, February 1957. (Mean based on period 1951-55.)
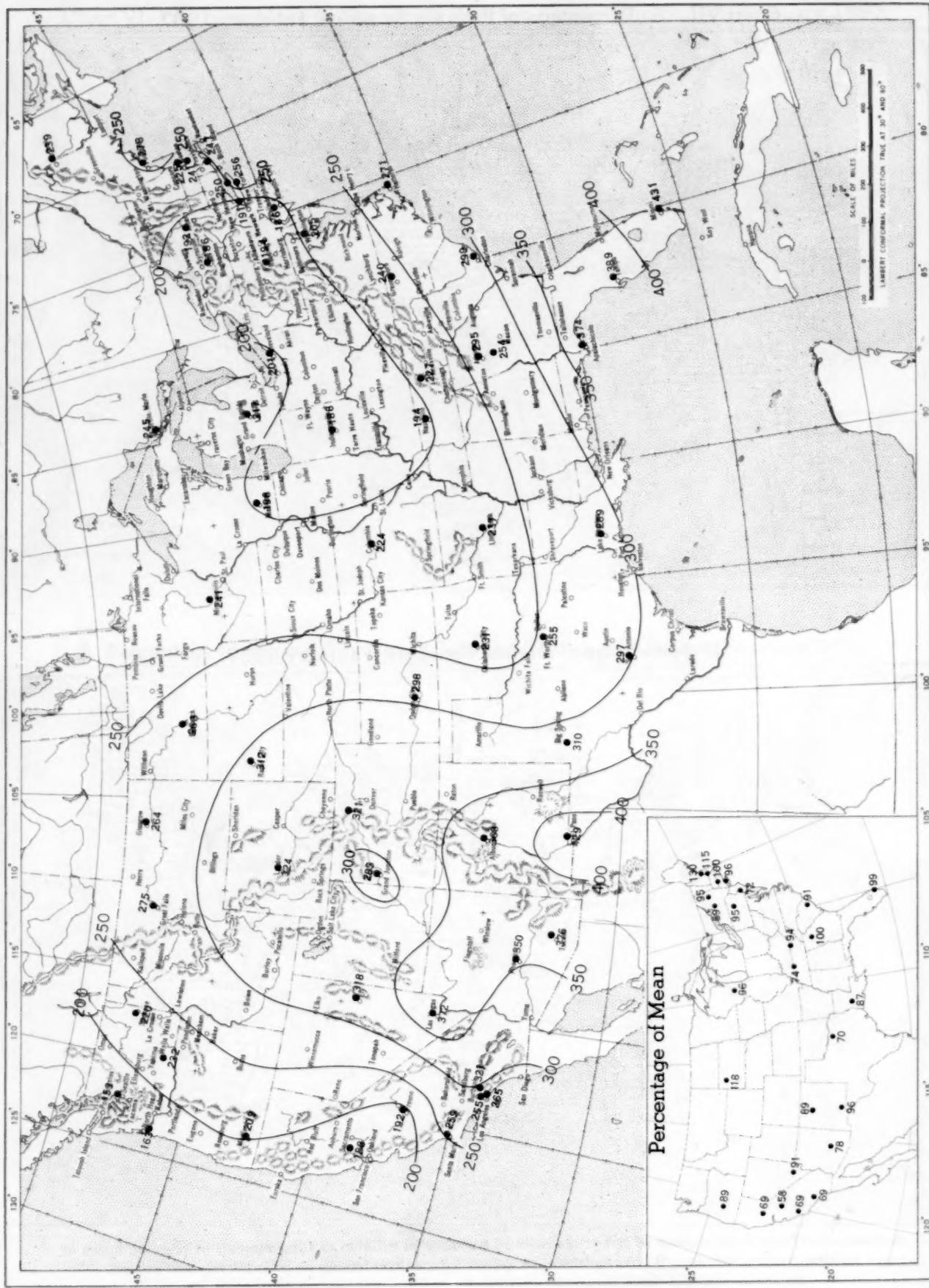

Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm.$^{-2}$). Basic data for isolines are obtained from supplementary data for which limits of accuracy are wider than for those data shown. Further estimates are shown on chart. The inset shows the percentage of the mean based on the period 1951-55.

The inset shows the percentage of the mean based on the period 1931-55.

Chart IX.   Tracks of Centers of Anticyclones at Sea Level, February 1957.
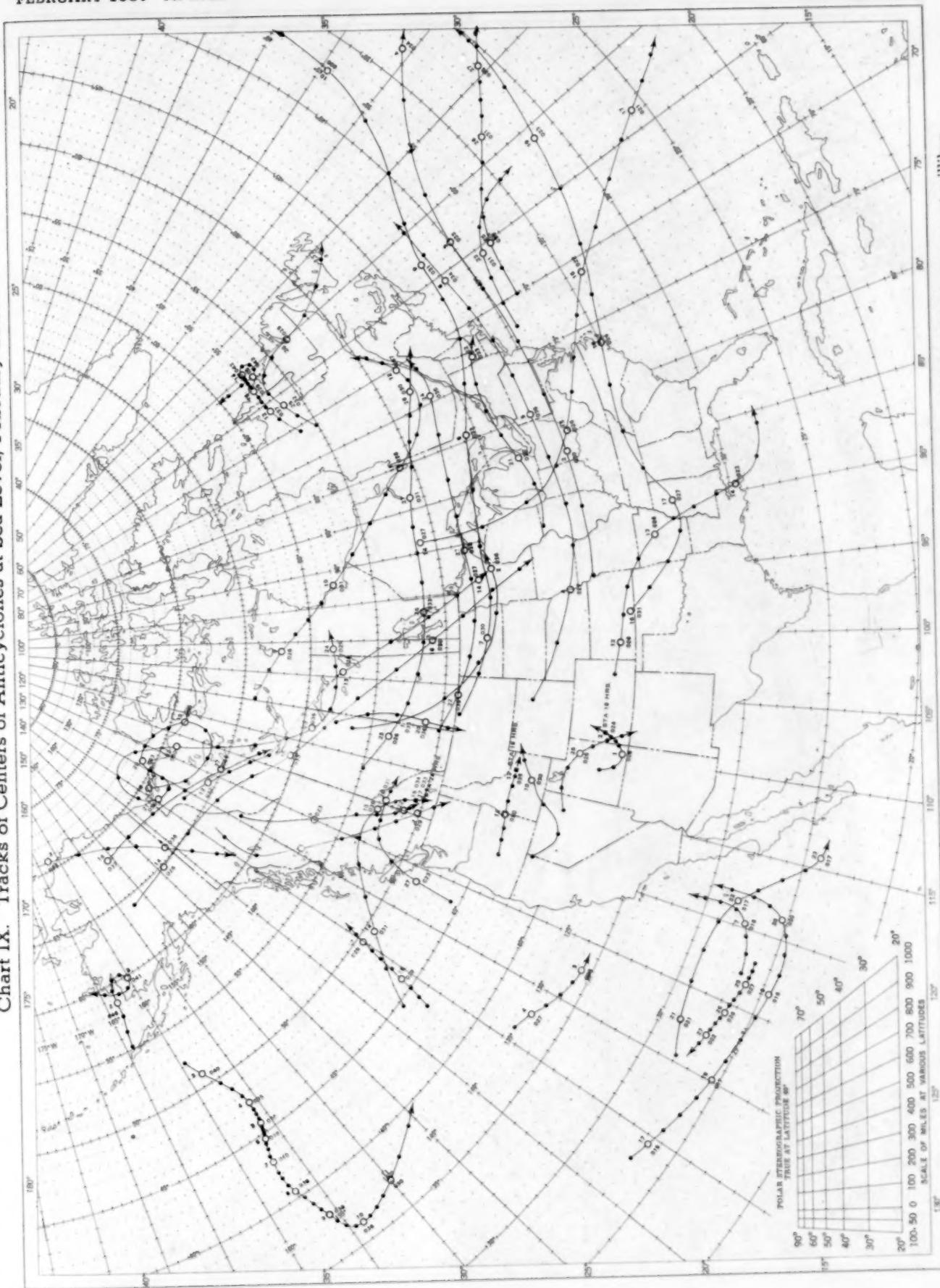
Circle indicates position of center at 7:30 a. m. E. S. T.   Figure above circle indicates date, figure below, pressure to nearest millibar.
Squares indicate position of stationary center for period shown.   Dashed line in track
Dots indicate intervening 6-hourly positions.   Only those centers which could be identified for 24 hours or more are included.
indicates reformation at new position.

POLAR STEREOGRAPHIC PROJECTION
TRUE AT LATITUDE 60°

SCALE OF MILES AT VARIOUS LATITUDES

Chart X. Tracks of Centers of Cyclones at Sea Level, February 1957.

POLAR STEREOGRAPHIC PROJECTION
TRUE AT LATITUDE 60°

SCALE OF MILES AT VARIOUS LATITUDES
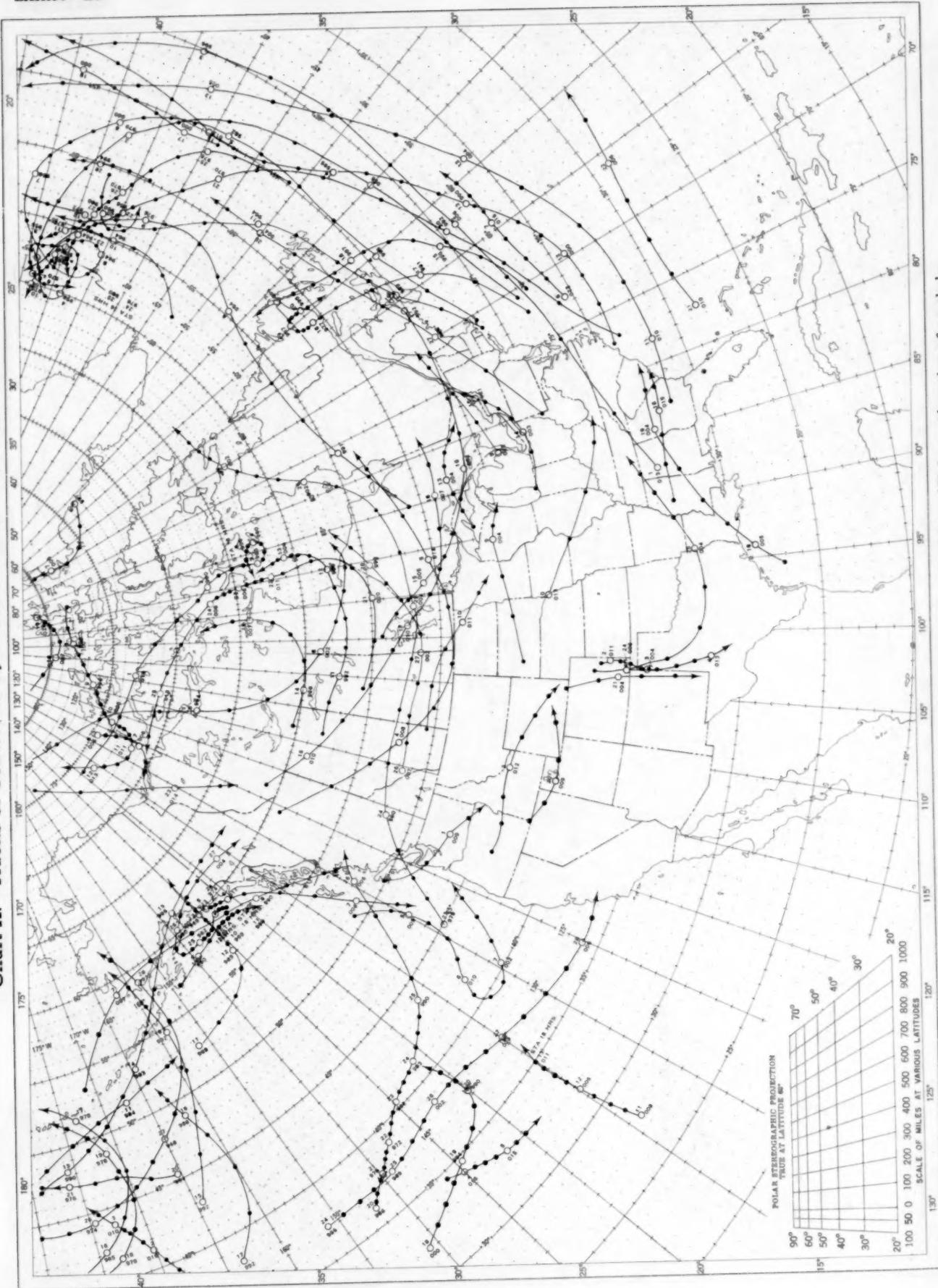
Circle indicates position of center at 7:30 a. m. E. S. T.   See Chart IX for explanation of symbols.

Chart XI.   Average Sea Level Pressure (mb.) and Surface Windroses, February 1957.   Inset: Departure of Average Pressure (mb.) from Normal, February 1957.

POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°

SCALE OF NAUTICAL MILES AT VARIOUS LATITUDES

Departure From Normal

25 HOURLY PERCENTAGES 25
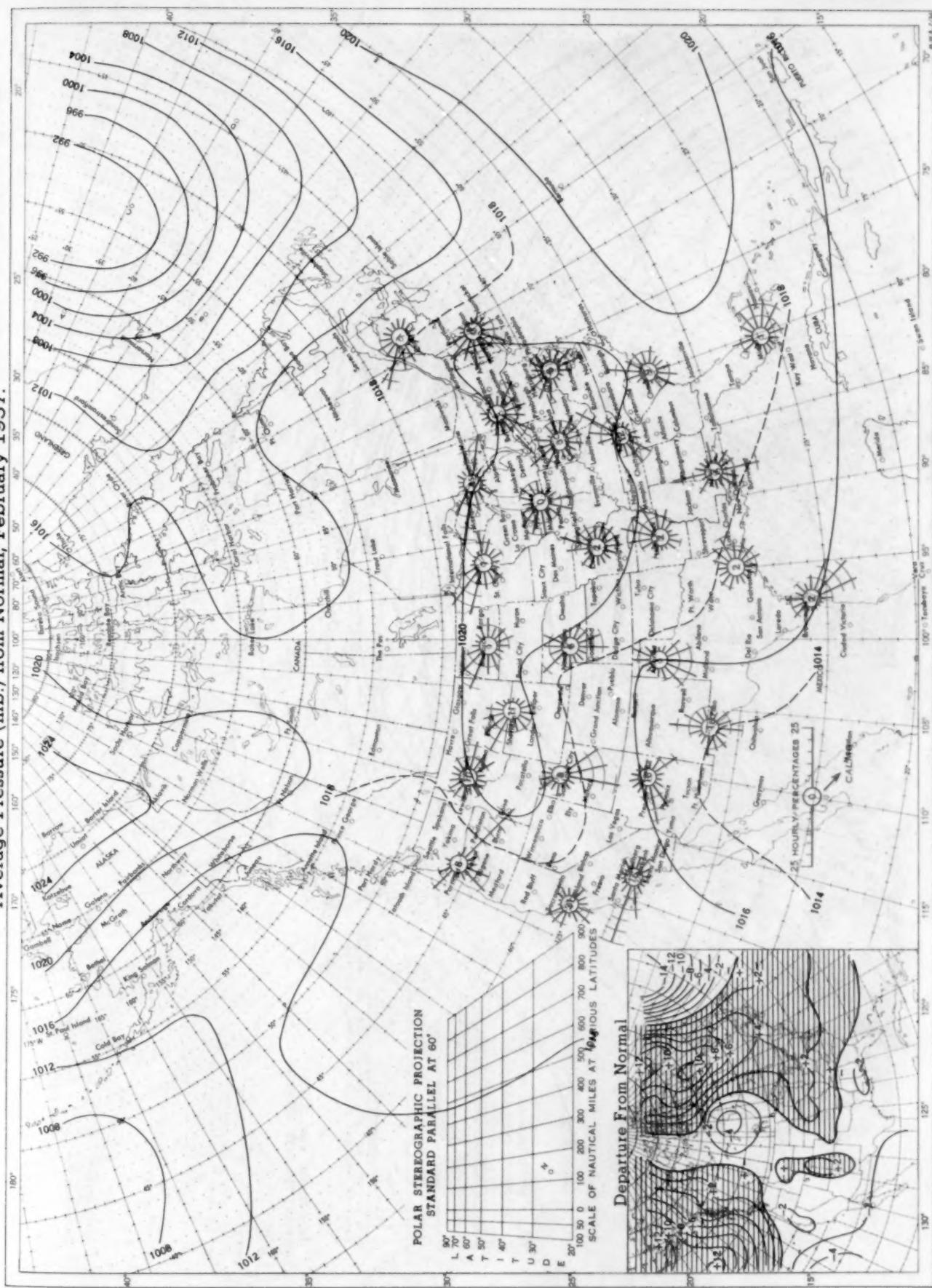
CALM

Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings.   Windroses show percentage of time wind blew from 16 compass points or was calm during the month.   Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. 850-mb. Surface, 0300 GMT, February 1957. Average Height and Temperature, and Resultant Winds.

POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°

SCALE OF NAUTICAL MILES AT VARIOUS LATITUDES

GEOSTROPHIC WIND SCALE
CONSTANT PRESSURE SURFACES

VELOCITY (KNOTS)
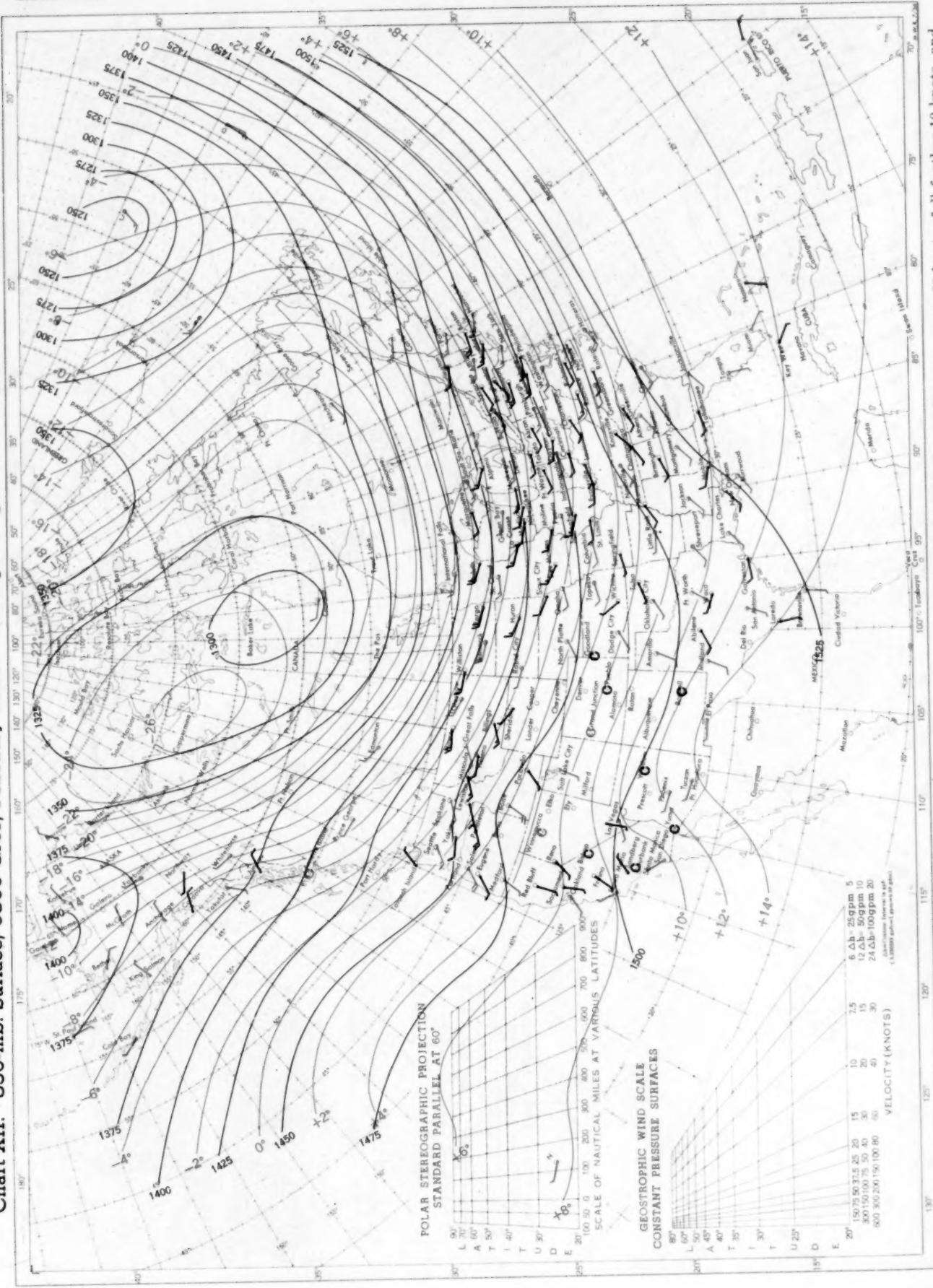
Height in geopotential meters (1 g. p. m. = 0.98 dynamic meters). Temperature in °C. Wind speed in knots; flag represents 50 knots, full feather 10 knots, and half feather 5 knots. Winds shown in red are based on rawins taken at the indicated pressure surface and time. Those in black are based on pibals taken at 2100 GMT and are for the nearest standard height level.

on pibals taken at 2100 GMT and are for the nearest standard height level.

Chart XIII.   700-mb. Surface, 0300 GMT, February 1957.   Average Height and Temperature, and Resultant Winds.

POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°

SCALE OF NAUTICAL MILES AT VARIOUS LATITUDES

GEOSTROPHIC WIND SCALE
CONSTANT PRESSURE SURFACES

VELOCITY (KNOTS)

See Chart XII for explanation of map.
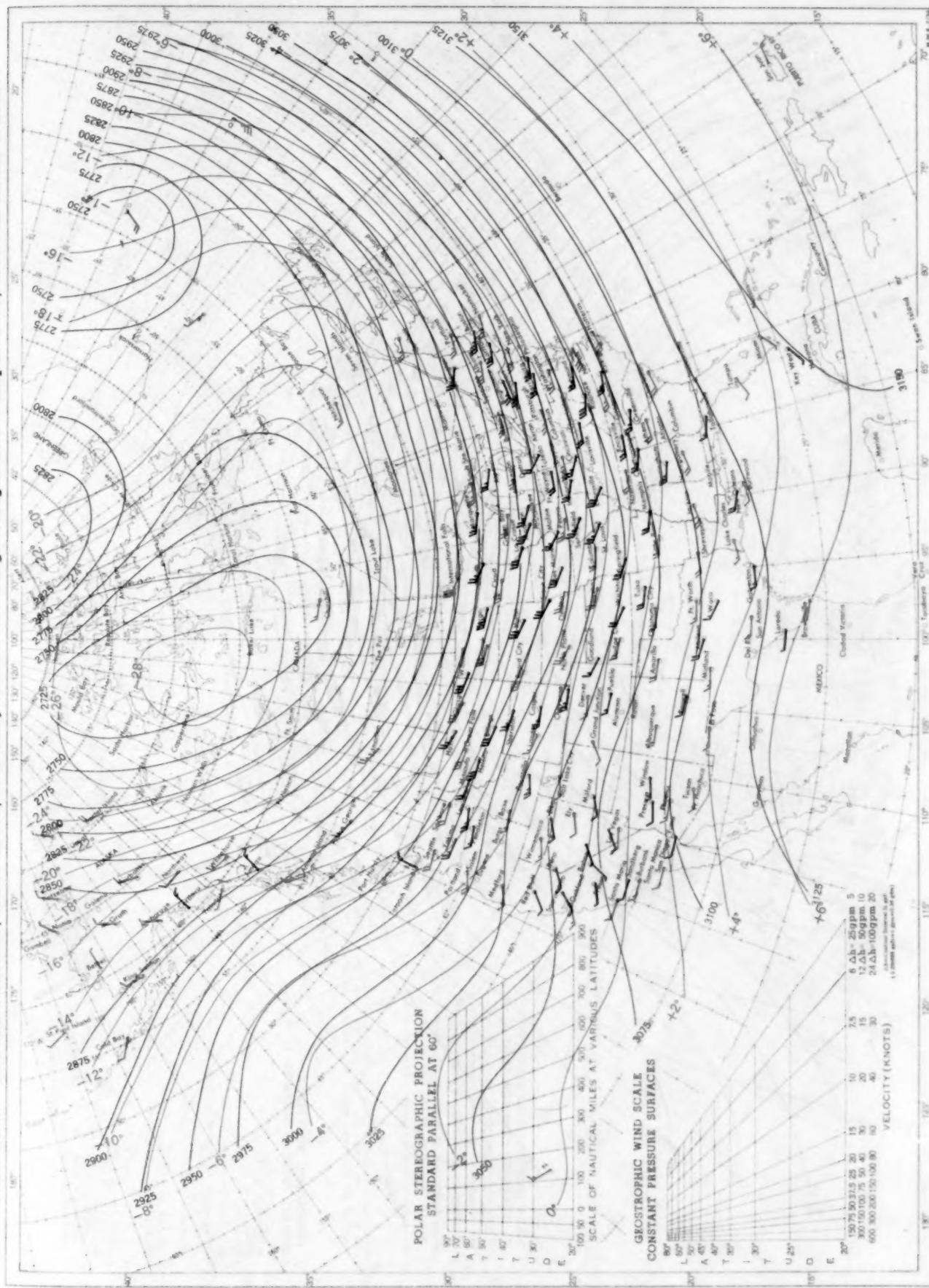
Chart XIV.   500-mb. Surface, 0300 GMT, February 1957.   Average Height and Temperature, and Resultant Winds.
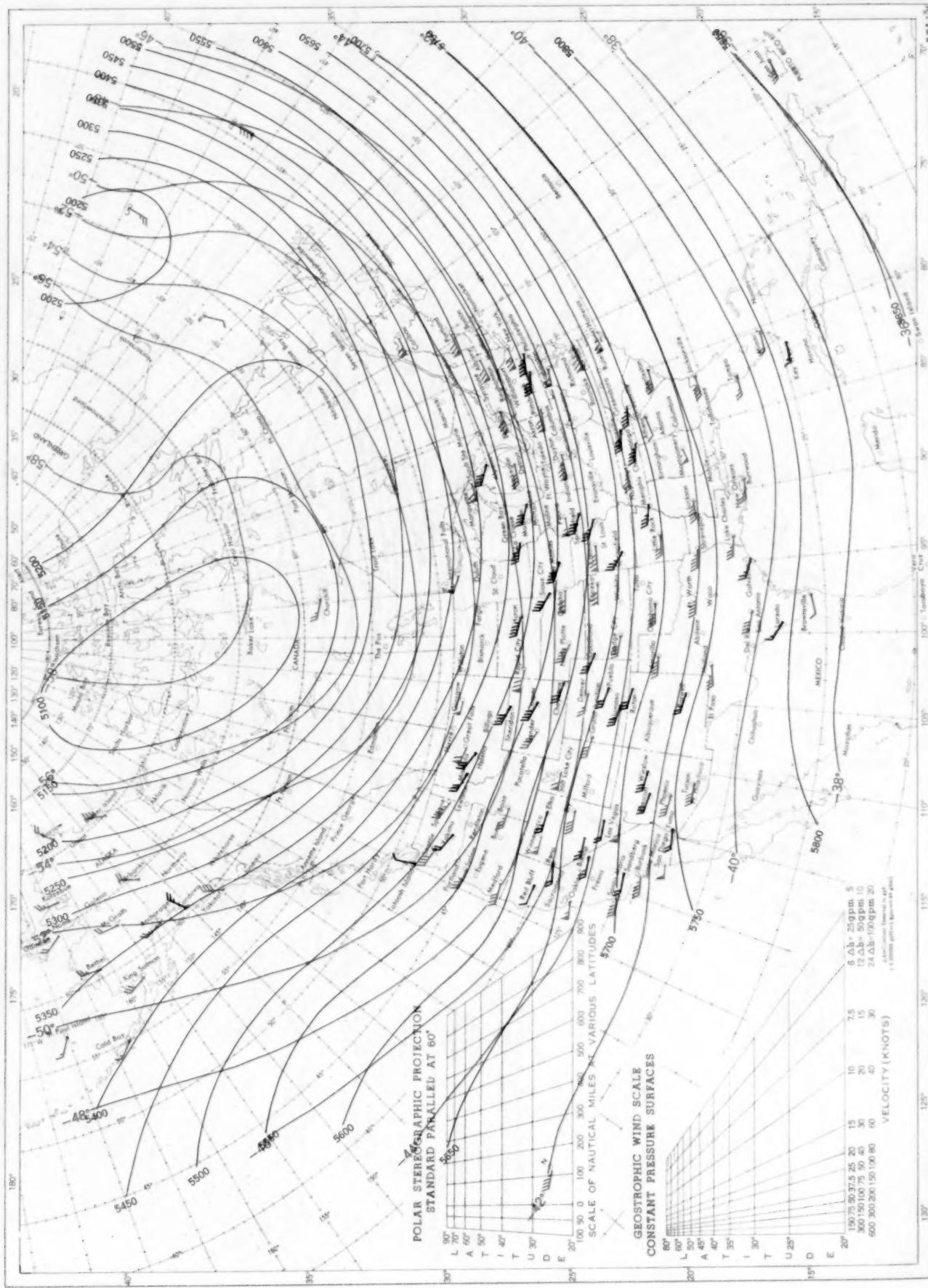
See Chart XII for explanation of map.

Chart XV.   300-mb. Surface, 0300 GMT, February 1957.   Average Height and Temperature, and Resultant Winds.
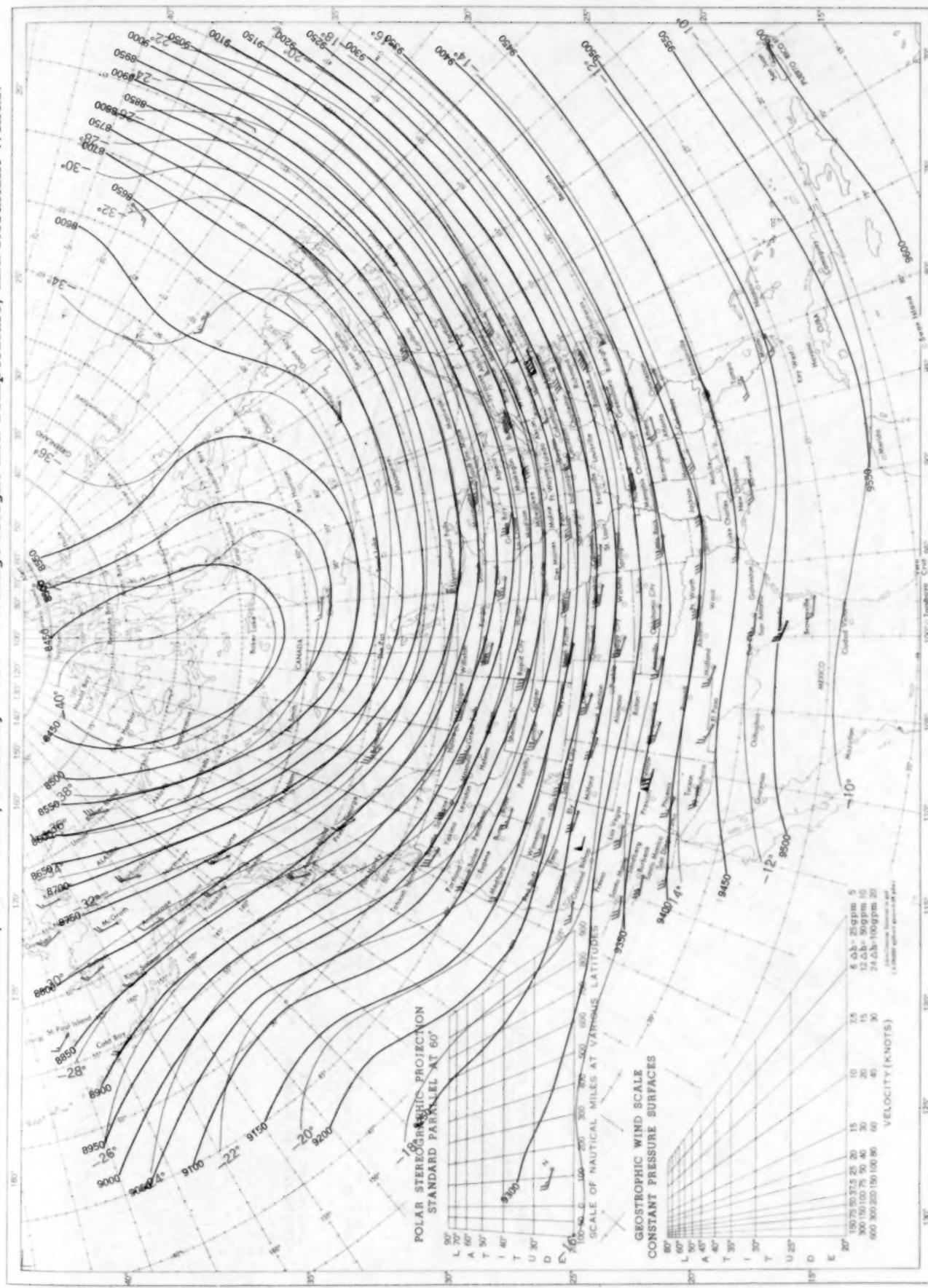
See Chart XII for explanation of map.

Chart XVI. 200-mb. Surface, 0300 GMT, February 1957. Average Height and Temperature, and Resultant Winds.

POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°

GEOSTROPHIC WIND SCALE
CONSTANT PRESSURE SURFACES

VELOCITY (KNOTS)
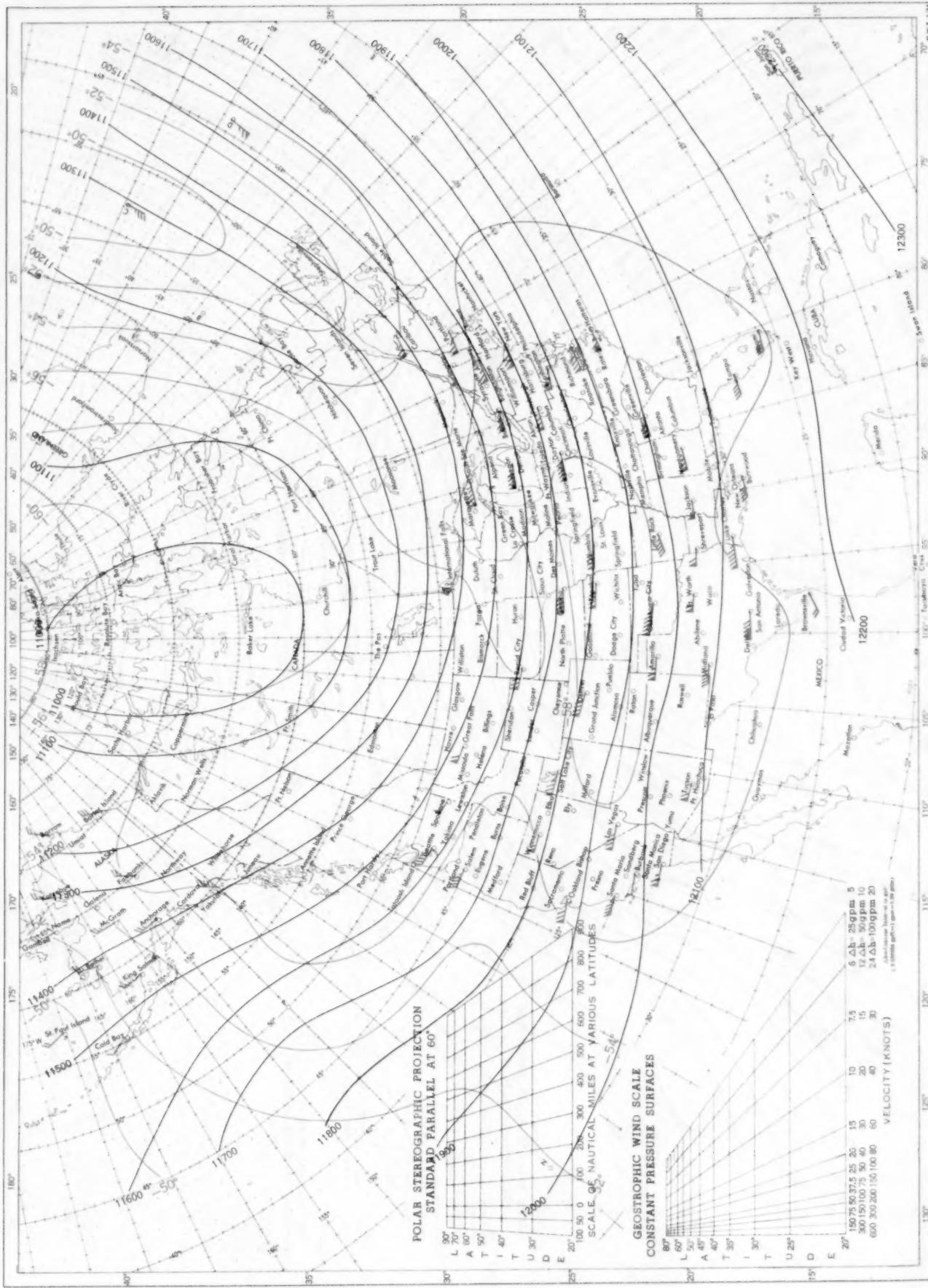
See Chart XII for explanation of map. All winds are from rawin reports.

Chart XVII.   100-mb. Surface, 0300 GMT, February 1957.   Average Height and Temperature, and Resultant Winds.

POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°

SCALE OF NAUTICAL MILES AT VARIOUS LATITUDES

GEOSTROPHIC WIND SCALE
CONSTANT PRESSURE SURFACES

VELOCITY (KNOTS)

See Chart XII for explanation of map.   All winds are from rawin reports.